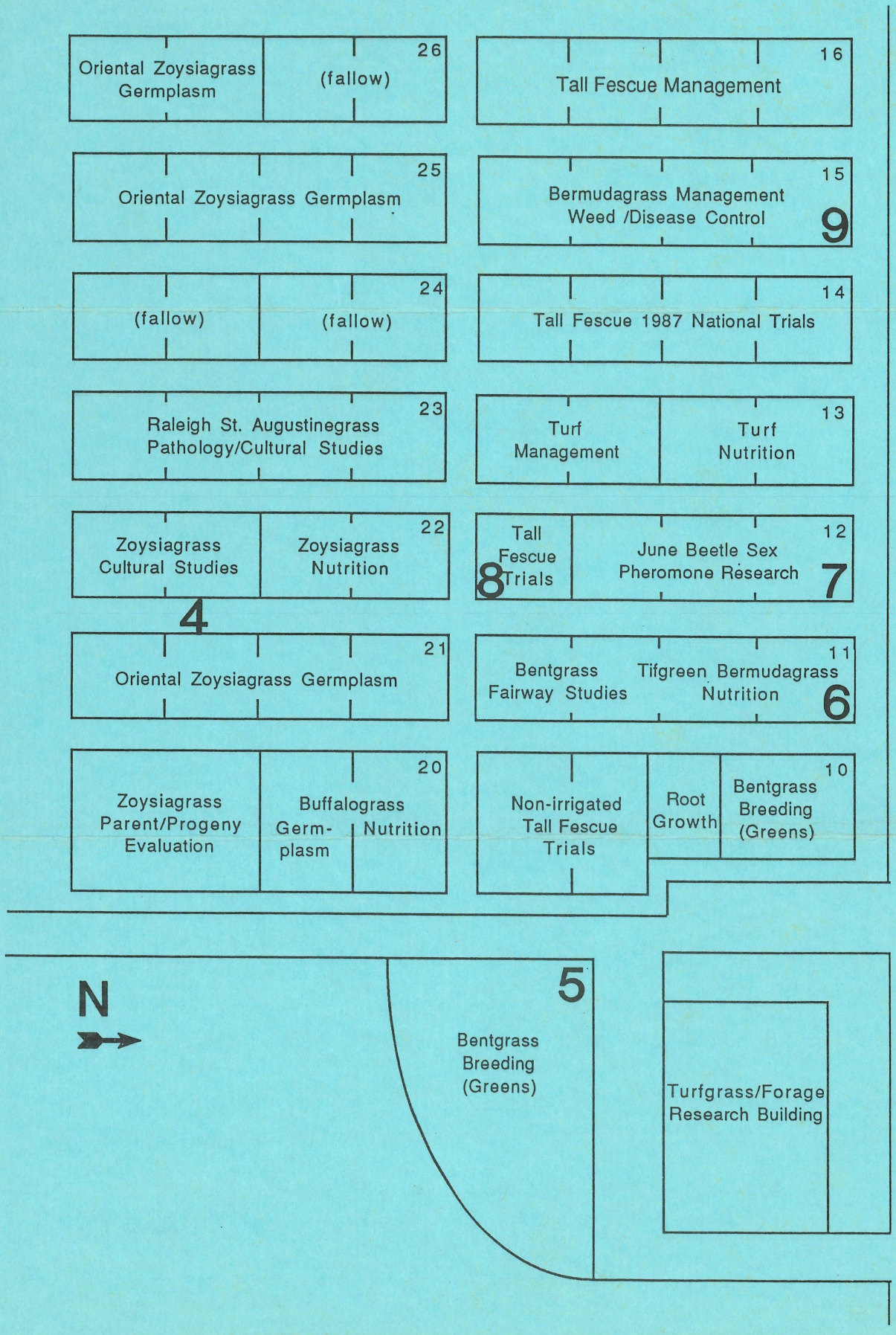
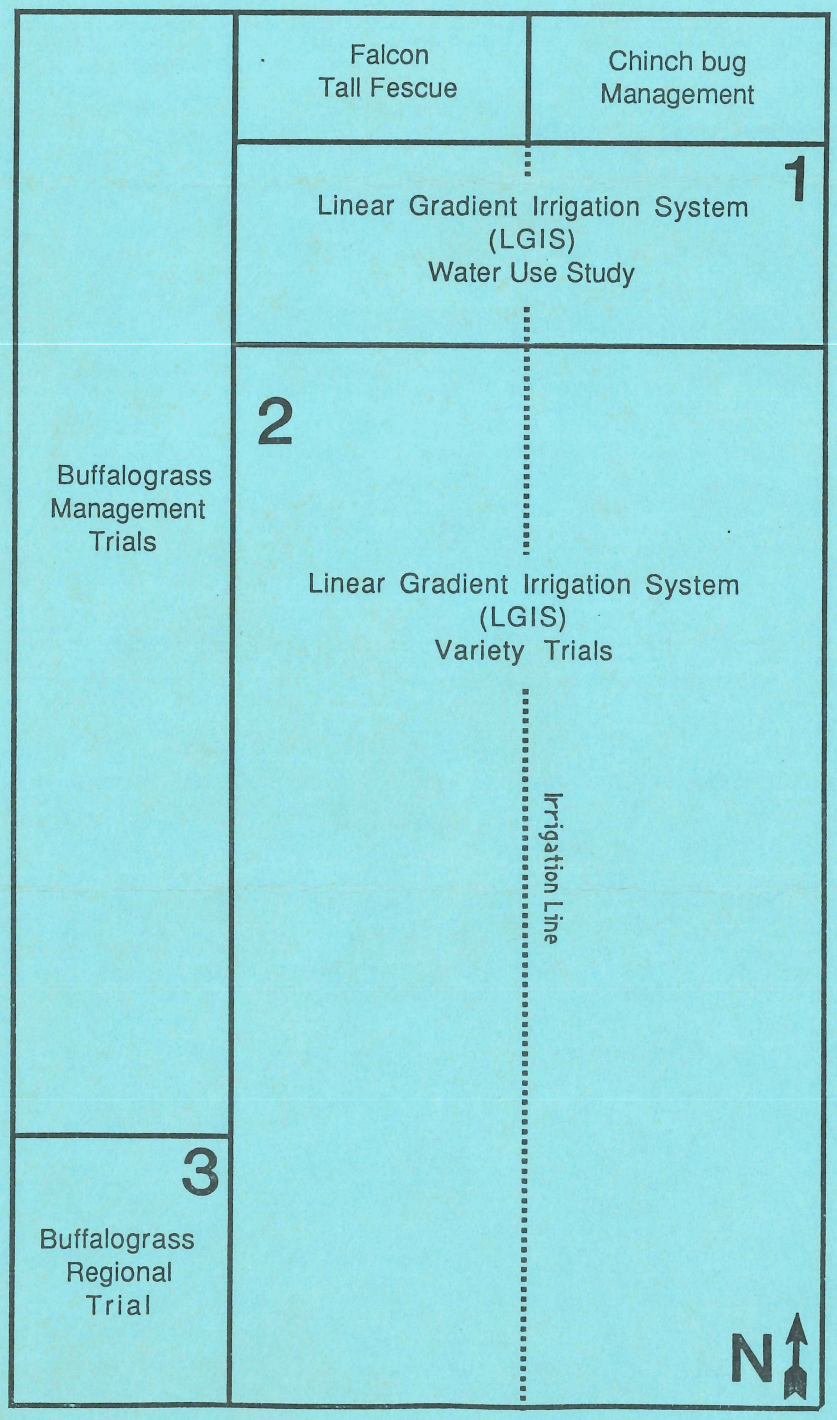
Texas A & M Turfgrass Field Research Facility

Initiated in 1980



Linear Gradient Irrigation System

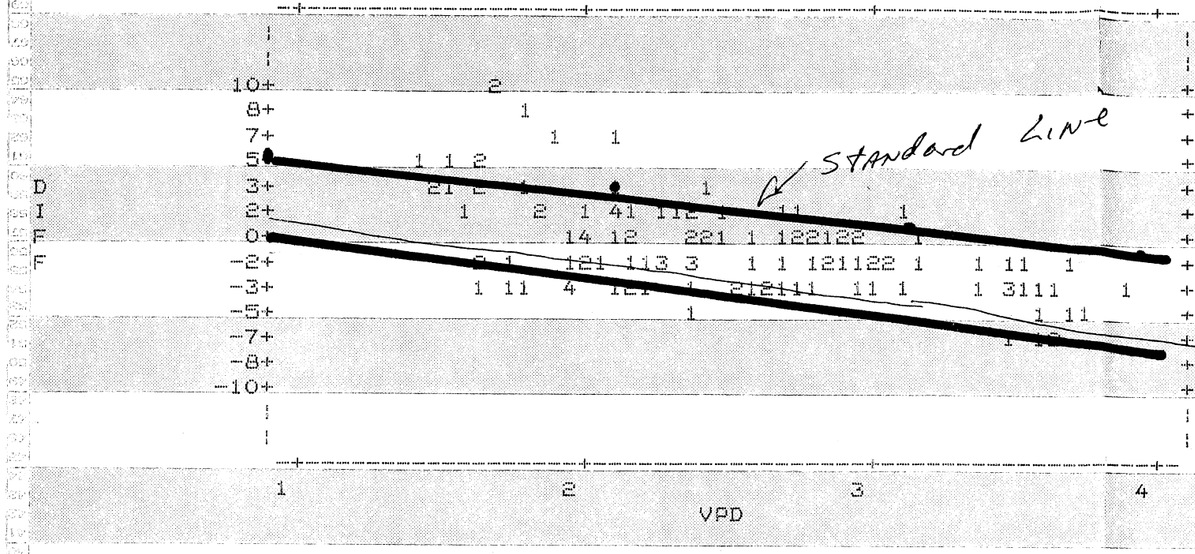
Established in 1986



Date/Time 02-25-1987 10:33:57
Data Base Name A:data
Description Imported from A:turf.dat

Scatter Plots

WINTER TURF DATA
X (VPD) by Y (DIFF) = Frequencies



7 - 1.9 * VPD upper = 13

2.0 - 1.9 * VPD upper = 8

OR

3.0 - 1.9 * VPD upper = 9

In order to comprehensively understand the behavior of the ST-27 index on turf grass, the following questions need to be answered There are six major categories of questions:

- Grass type/mixtures
- Management Practices/Design Considerations
- Soil Water
- Theoretical
- Interpretation
- Agronomic

Grass Type/Mixtures

- how does grass type (cool season, warm season),species (bermudas, fescue, etc) and variety affect the index?
grass specie-- (bermuda, fesuce, St. Augustine, etc., etc.)
grass variety-- (Penncross bermuda, Emerald bermuda , Toronto bermuda, etc, etc, etc, for each grass specie).

- What is the effect of grass mixtures on the turf index?

- How does naturally occuring dormancy affect the index? What is the effect of a mixture of dormant and rapdily growing species on the index?

Management Practices/Design Considerations

- Grass useage--is the grass subjected to frequent traffic, such as a practice putting green, or is it seldom walked on (parks) by comparison?

- cutting height--given that all other factors remain the same, how does cutting height affect the index?

- does the type/sharpeness of lawn mower used to cut the turf have an effect?

- how much do grass clippings (of what density?) affect the index?

- What effect does thatch have? how does this effect interact with Plant type, plant thickness, and surface wetness?

- What is the effect of variations in plant density? How does this effect interact with surfact soil wetness or dryness? How does this effect interact with windspeed?

- how does slope and aspect affect the index? Are differences in the index on sloped areas versus flat areas the result of seeing more thatch/soil or is there also a "real" effect, i.e., do sloped areas actual experience more(or less) stress, depending on their exposure to the sun? How does this affect index readings/mangement concerns on a green?

Benson,

I have received, we should visit briefly about this subject.

Steve

• cultivation practices--how does coring, top-dressing, vertical mowing, matting, adding wetting agents, etc. affect the index?

•What is the optimum irrigation timing sequence for a given type of turf, as a function of soil type, location, and useage? Can these timing sequences be inferred from index readings? How can "optimum" be defined?

•What management solutions are available for localized "hot spots" identified by the ST-27? Irrigating a hot spot via adjusted sprinkler patterns may result in waterlogging adjacent areas, which in turn would make the adjacent areas warmer. How detrimental is this? Must a green be rebuilt in order to effectively eliminate some hot-spots?

• what effect does mowing frequency have on the index?

• how does syringing interact with the index? Can the index be used after a syringing for any useful purpose?

• can sprinkler head distribution patterns be effectively judged with the index? How?

Soil Water

• how do index readings compare with tensiometer/soil moisture readings?

• how does salinity in the soil and water affect the index ?

• What is the effect of soil PH on the index?

• What is the relationship between morning dew patterns and afternoon turf temperature patterns? Morning dew patterns represent a competiting technology to find the dry spots on a green.

This is not A technology it is A phenotipic method. Subjective method. ("Best guess")

• What is the effect of soil oxygen depletion on the index? How long does this effect last? How long does it take for this effect to produce changes in visual quality (low index numbers, with poor visual characteristics).

• irrigation practices--how does the style of irrigation interact with index values ? How dependent is this on site specific soil characteristics and climatic conditions?

Theoretical

• What effect does windspeed have on the index? Under what conditions?

• What is the effect of air temperature on all the above interactions?

• how do index readings compare with soil temperature readings?

Interpretation

. is a turf with poor visual qualities, but low index readings currently in the "recovery" mode?

. how long does it take a particular grass species to recover good visual appearance after its visual characteristics have been impaired? How does this interact with the index?

. what is the best standard with which to compare visual quality and agronomic health between turf located at different sites?

. how does over-irrigation impact the index and turf quality, especially over time? Does this predispose an area to having problems if water supplies suddenly become restricted?

. visual quality--what is the relationship between visual quality , the turf index and all the above variables.

Agronomic Concerns

.disease effects on turf temperature -- is the disease fast acting (overnight) or does it develop over time, with a corresponding effect on plant temperatures? Does the disease affect plant temperatures?

. fertilizer effects--what is the effect on plant temperatures of turf that is short in N,P,K or various micronutrients?

. chemical effects--what happens to plant temperatures when various funsicides and insecticides are applied?

.How does the index work on grasses which grow primarily in the shade?

. What is the optimum rooting depth for a turf species? Can rooting depth be controlled with the index? How does time of year interact with this objective?

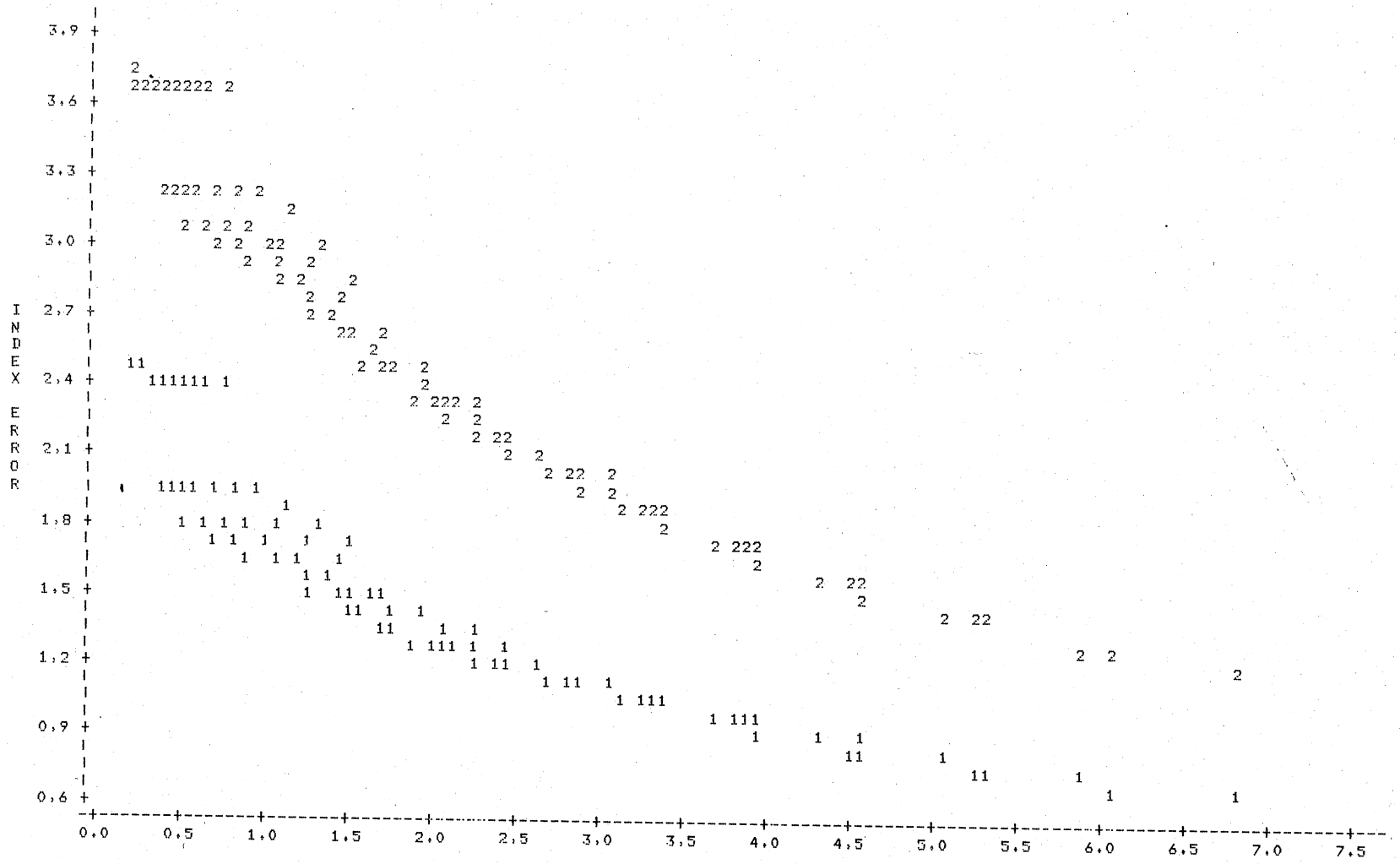
. How does the optimum biological temperature of a grass species interact with the index and all the above? What is the optimum biological temperature for a given grass species, or grass mixture?

. what is the effect of auotrphic and heterotrophic bacteria?

? & I don't understand.

ANALYSIS OF TURF INDEX ERRORS TRENDS
ERROR IN TA= 3 C (5 F) , ERROR IN RH= 5%
ERROR IN TC-TA IS 1 OR 2 C

PLOT OF IERR*VPD SYMBOL IS VALUE OF DTE

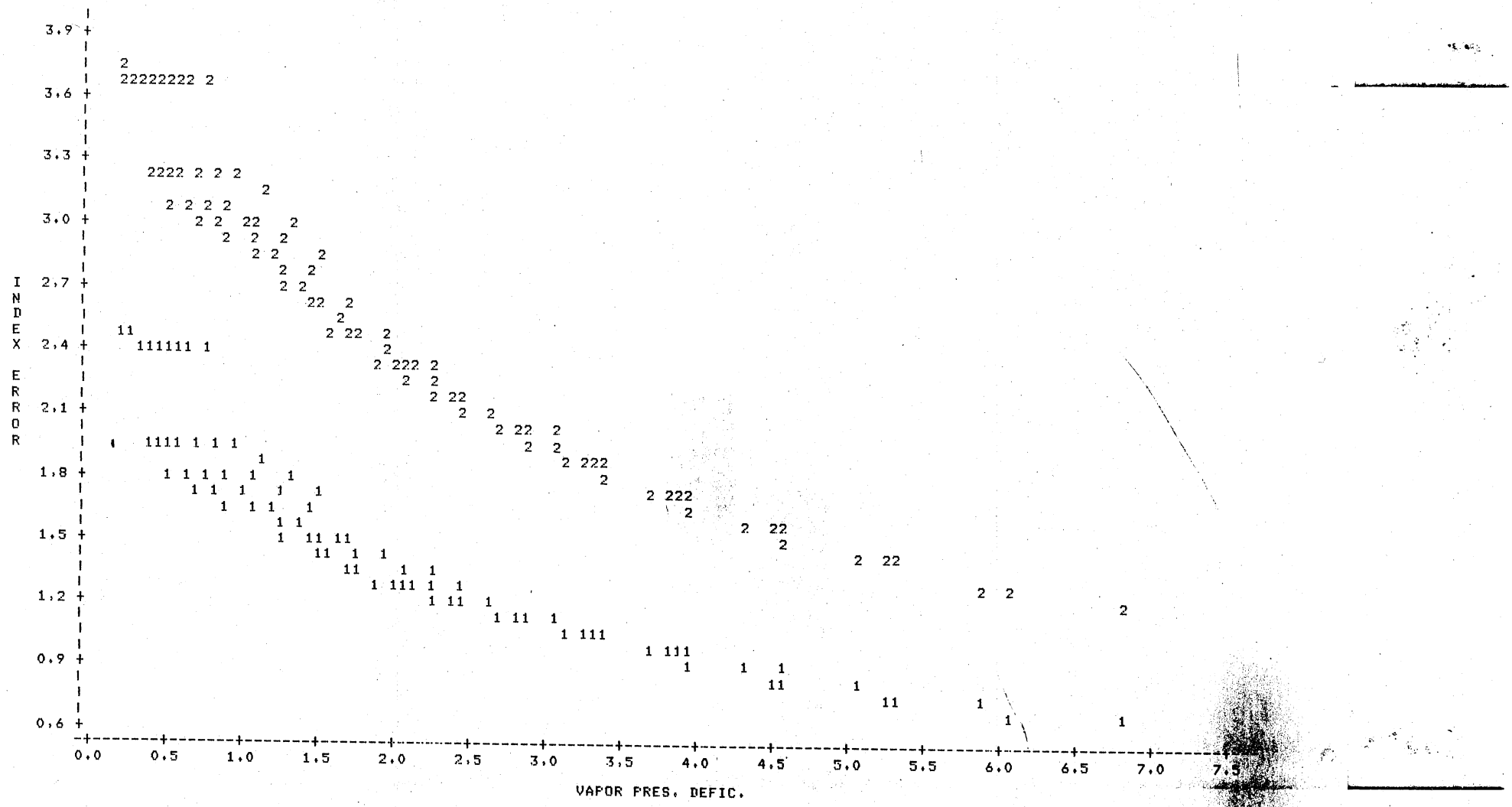


NOTE: 170 OBS HIDDEN

ANALYSIS OF TURF INDEX ERRORS TRENDS
ERROR IN TA= 3 C (5 F) , ERROR IN RH= 5%
ERROR IN TC-TA IS 1 OR 2 C

10:46 WEDNESDAY, SEPTEMBER 23, 1987 2

PLOT OF IERR*VPD SYMBOL IS VALUE OF DTE

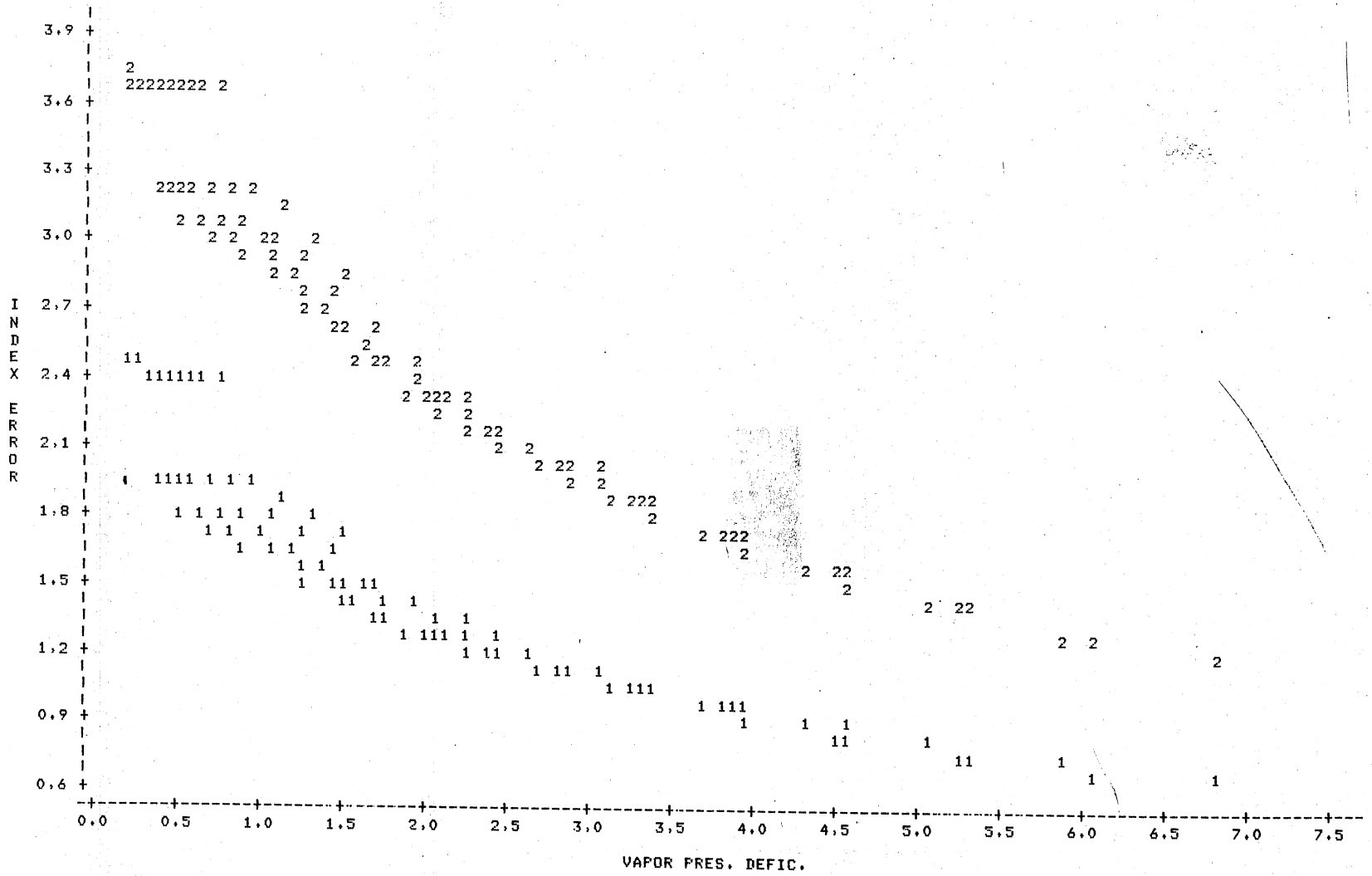


NOTE: 170 OBS HIDDEN

ANALYSIS OF TURF INDEX ERRORS TRENDS
ERROR IN TA= 3 C (5 F) , ERROR IN RH= 5%
ERROR IN TC-TA IS 0.5,1, 2, 3, OR 4 C

10:46 WEDNESDAY, SEPTEMBER 23, 1987 2

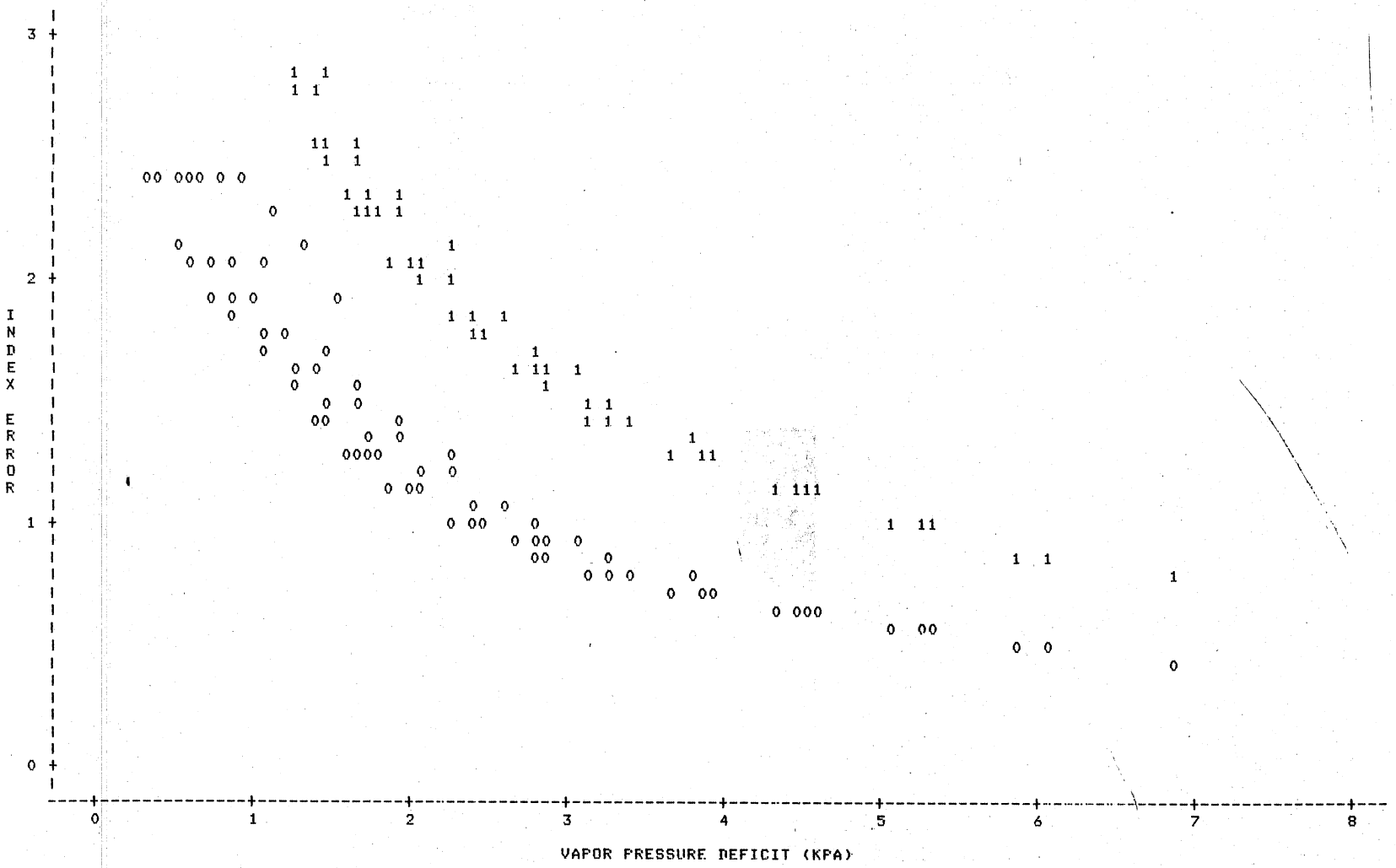
PLOT OF IERR*VPD SYMBOL IS VALUE OF DTE



NOTE: 170 OBS HIDDEN

ANALYSIS OF TOMATO INDEX ERRORS TRENDS IN PREDICTING AN INDEX OF 2
ERROR IN TA= ,5 C (1 F) , ERROR IN RH= 5%
ERROR IN TC-TA IS 0.5 OR 1 C
REFERENCE FOR A SCHEDULER WHICH IS EQUILIBRATED PROPERLY

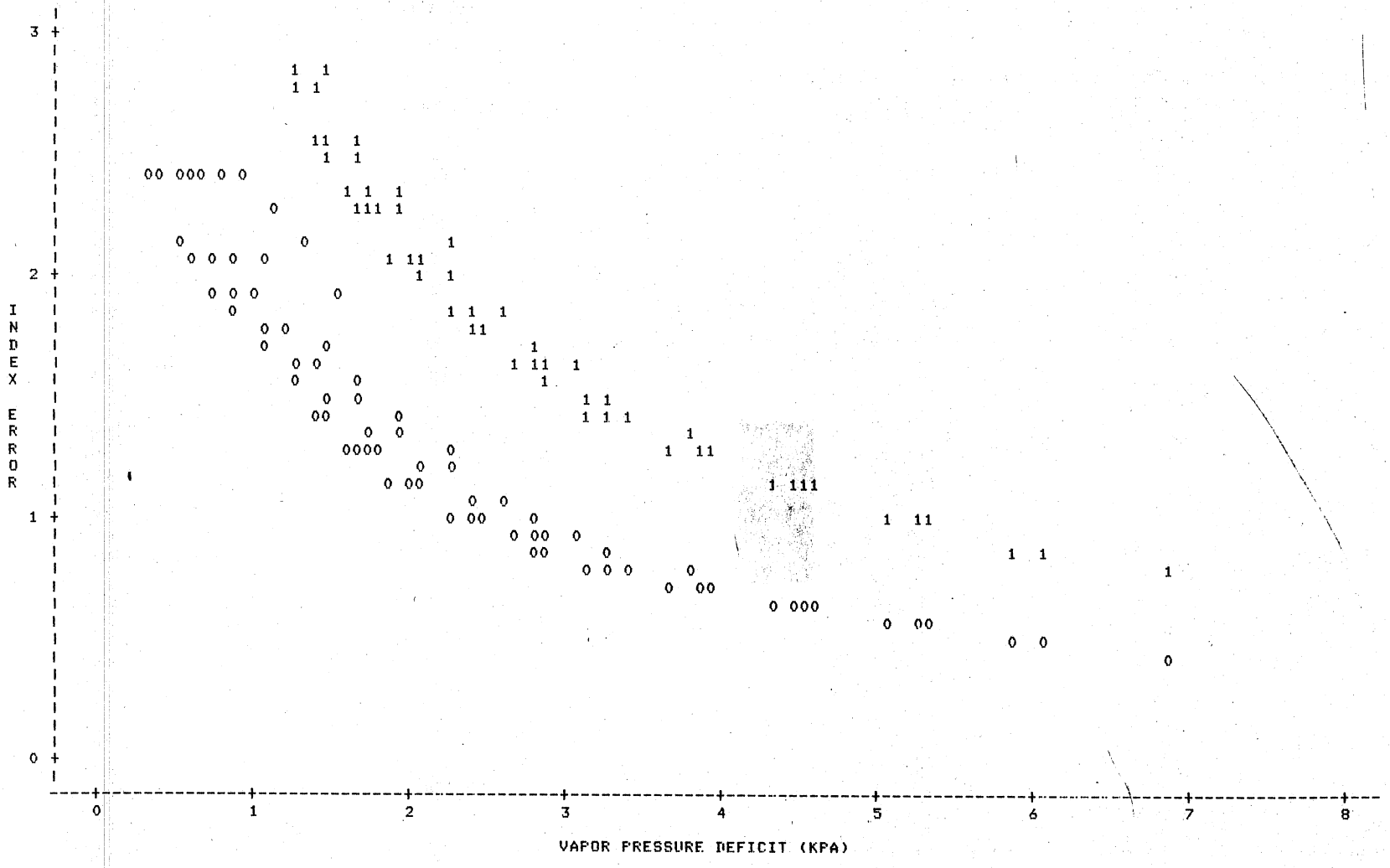
PLOT OF IERR*VPD SYMBOL IS VALUE OF DTE



NOTE: 42 OBS HAD MISSING VALUES OR WERE OUT OF RANGE 70 OBS HIDDEN

ANALYSIS OF TOMATO INDEX ERRORS TRENDS IN PREDICTING AN INDEX OF 2
ERROR IN TA= ,5 C (1 F) , ERROR IN RH= 5%
ERROR IN TC-TA IS 0.5 OR 1 C
REFERENCE FOR A SCHEDULER WHICH IS EQUILIBRATED PROPERLY

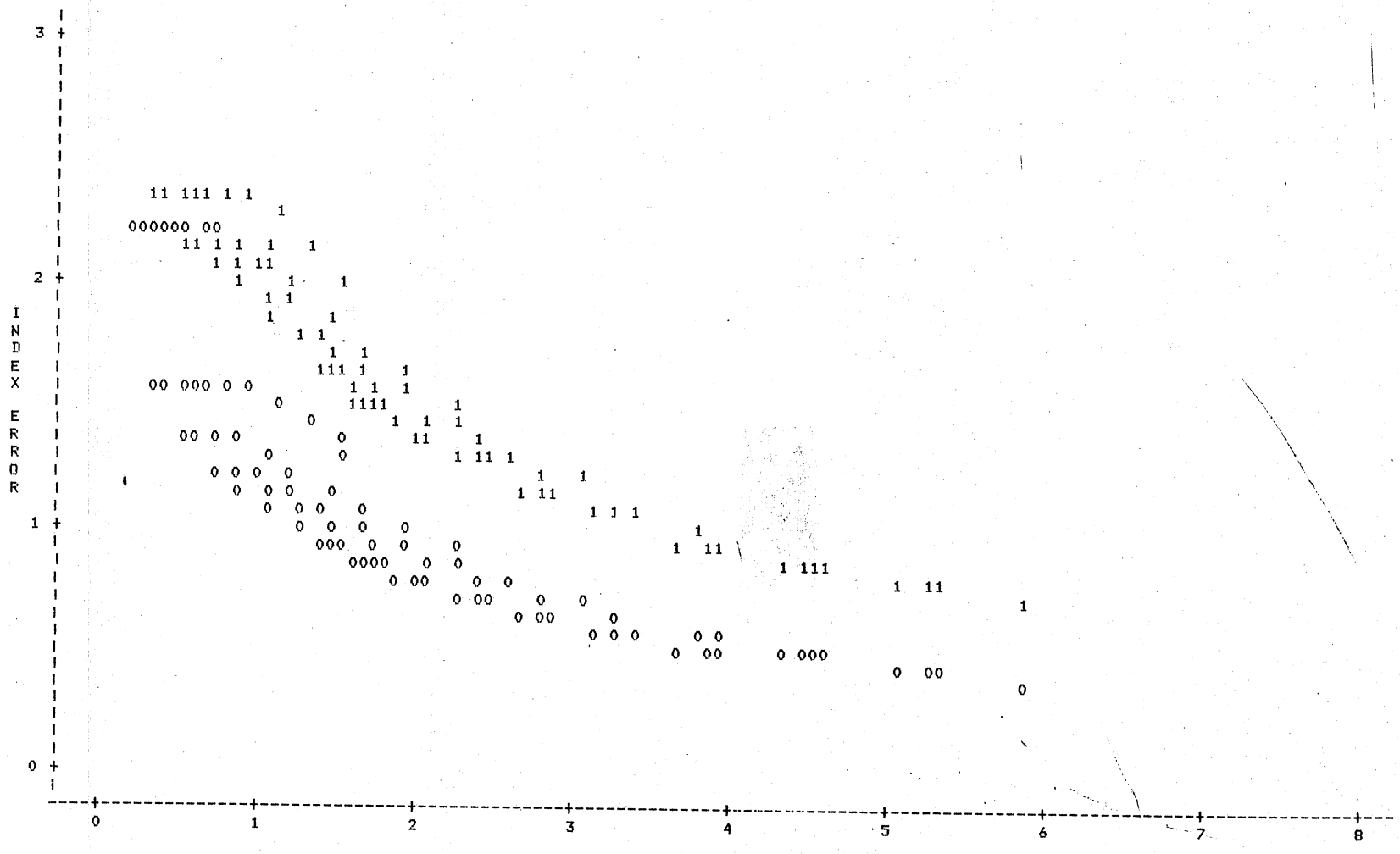
PLOT OF IERR*VPD SYMBOL IS VALUE OF DTE



NOTE: 42 OBS HAD MISSING VALUES OR WERE OUT OF RANGE 70 OBS HIDDEN

ANALYSIS OF WHEAT #1 INDEX ERRORS TRENDS IN PREDICTING AN INDEX OF 2
ERROR IN TA= ,5 C (1 F) , ERROR IN RH= 5%
ERROR IN TC-TA IS 0.5 OR 1 C
REFERENCE FOR A SCHEDULER WHICH IS EQUILIBRATED PROPERLY

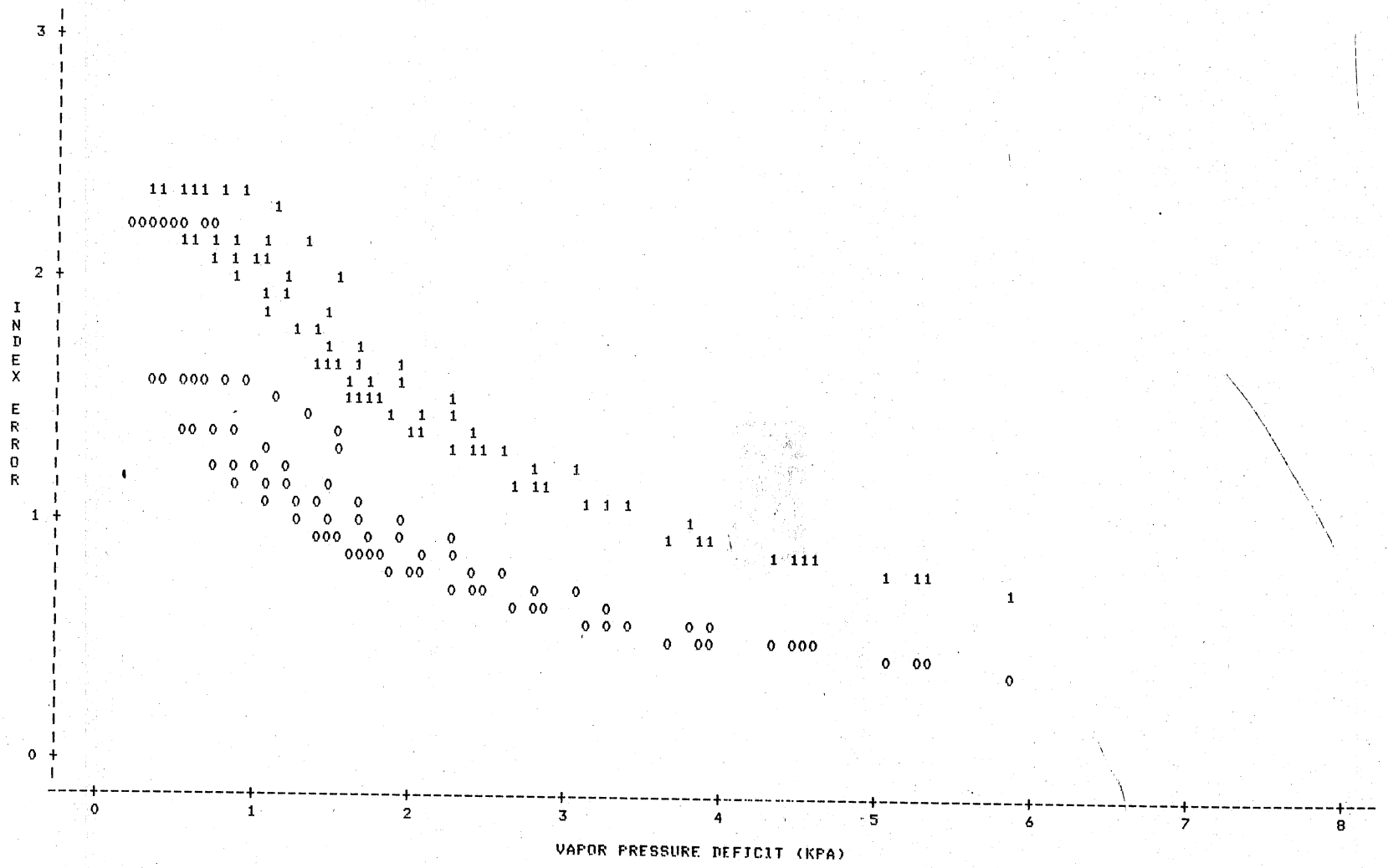
PLOT OF IERR*VPD SYMBOL IS VALUE OF DTE



NOTE: 10 OBS HAD MISSING VALUES OR WERE OUT OF RANGE 120 OBS HIDDEN

ANALYSIS OF WHEAT #1 INDEX ERRORS TRENDS IN PREDICTING AN INDEX OF 2
ERROR IN TA= .5 C (1 F) , ERROR IN RH= 5%
ERROR IN TC-TA IS 0.5 OR 1 C
REFERENCE FOR A SCHEDULER WHICH IS EQUILIBRATED PROPERLY

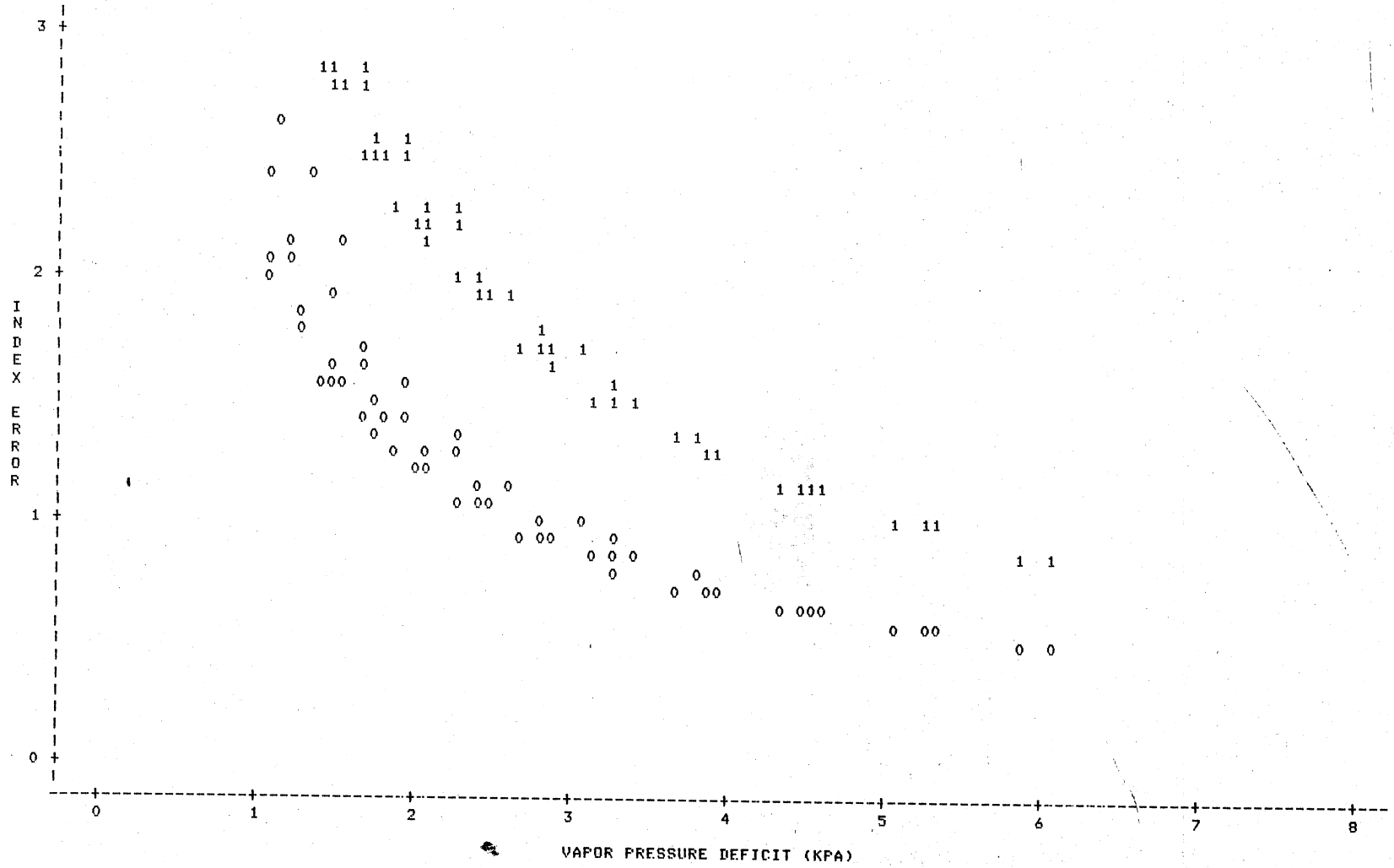
PLOT OF IERR*VPD SYMBOL IS VALUE OF DTE



NOTE: 10 OBS HAD MISSING VALUES OR WERE OUT OF RANGE 120 OBS HIDDEN

ANALYSIS OF COTTON INDEX ERRORS TRENDS IN PREDICTING AN INDEX OF 2
ERROR IN TA= .5 C (1 F) , ERROR IN RH= 5%
ERROR IN TC-TA IS 0.5 OR 1 C
REFERENCE FOR A SCHEDULER WHICH IS EQUILIBRATED PROPERLY

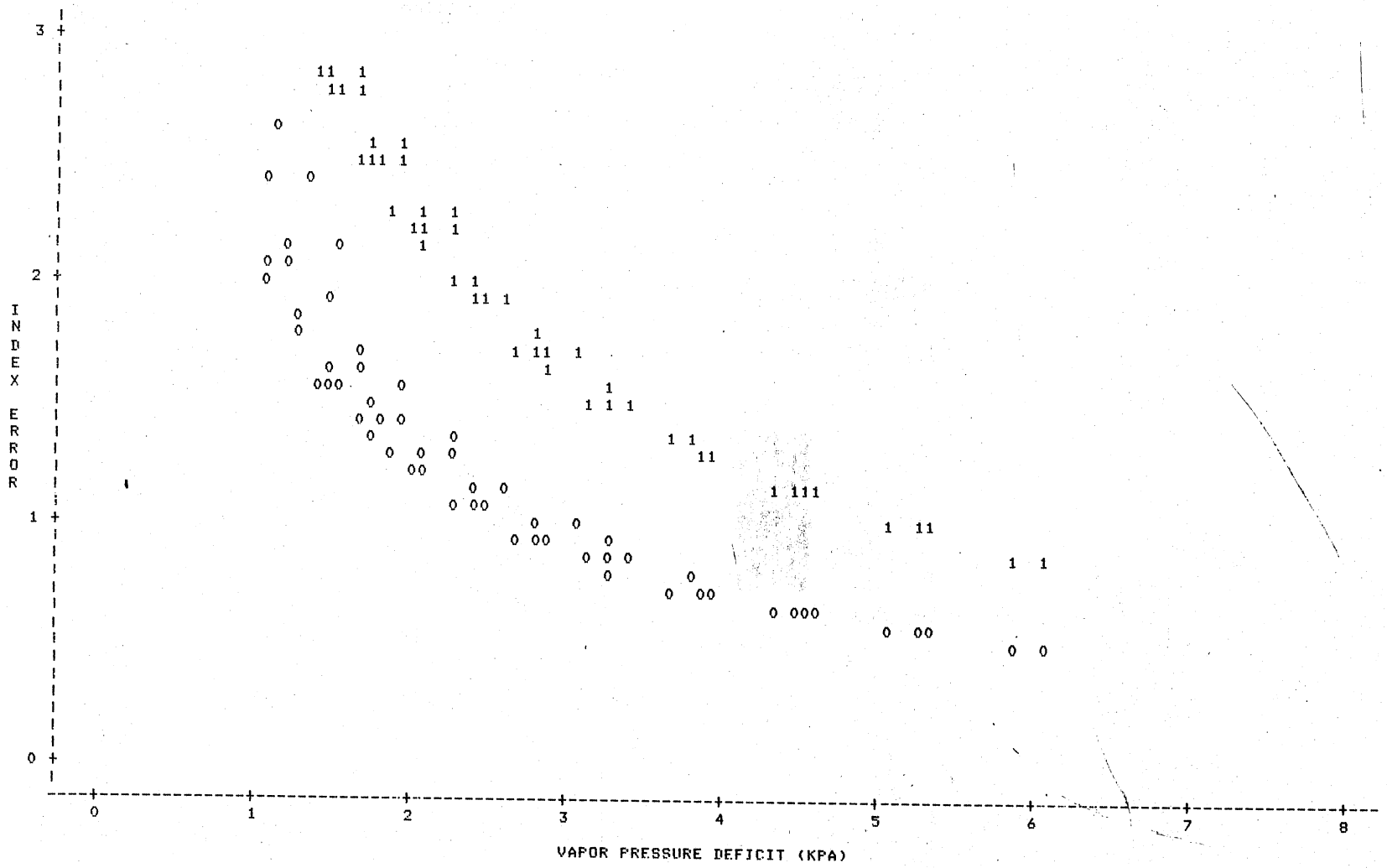
PLOT OF IERR*VPD SYMBOL IS VALUE OF DTE



NOTE: 11 OBS HAD MISSING VALUES OR WERE OUT OF RANGE 53 OBS HIDDEN

ANALYSIS OF COTTON INDEX ERRORS TRENDS IN PREDICTING AN INDEX OF 2
ERROR IN TA= .5 C (1 F) , ERROR IN RH= 5%
ERROR IN TC-TA IS 0.5 OR 1 C
REFERENCE FOR A SCHEDULER WHICH IS EQUILIBRATED PROPERLY

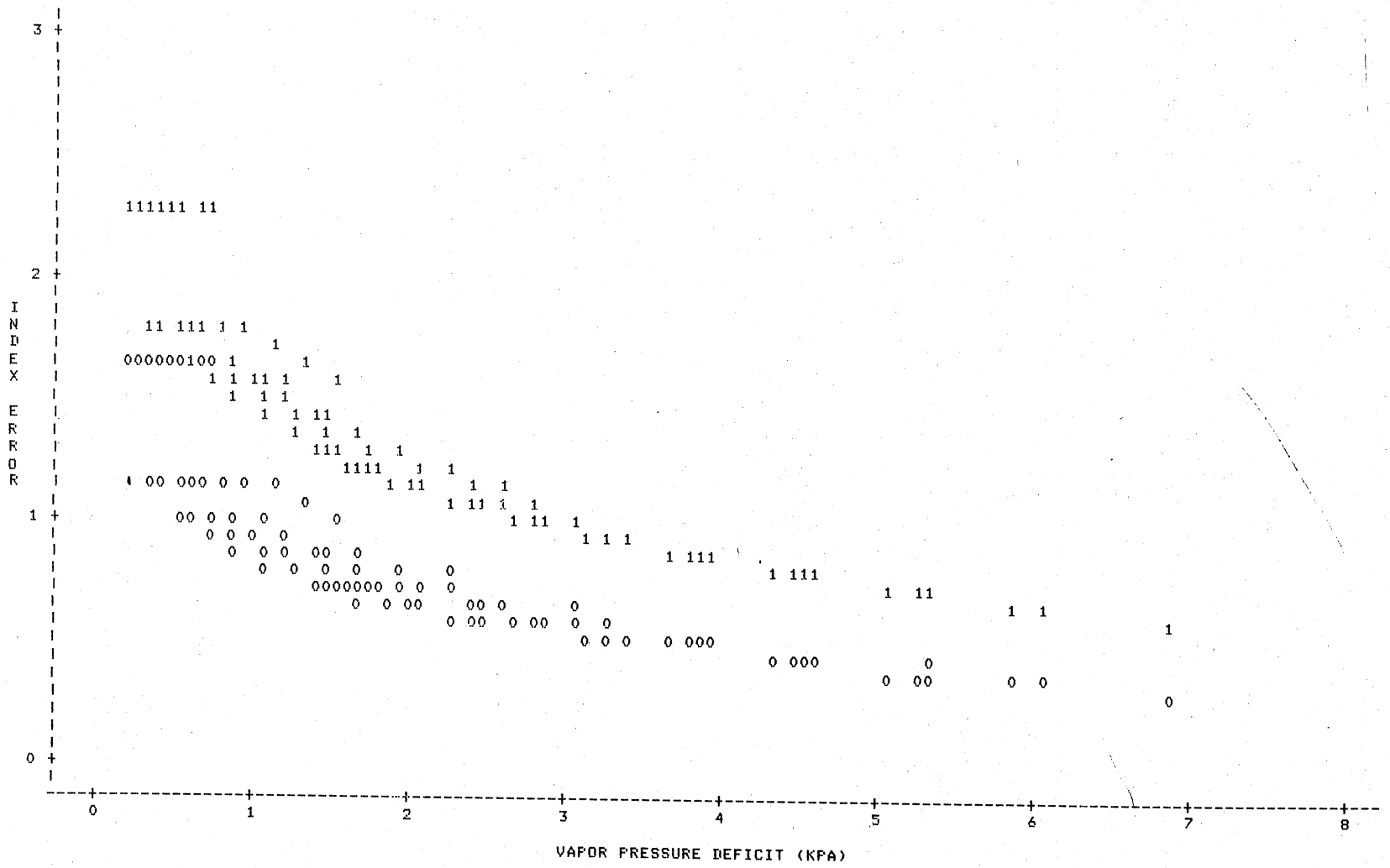
PLOT OF IERR*VPD SYMBOL IS VALUE OF DTE



NOTE: 11 OBS HAD MISSING VALUES OR WERE OUT OF RANGE 53 OBS HIDDEN

ANALYSIS OF TURF INDEX ERRORS TRENDS IN PREDICTING AN INDEX OF 2
ERROR IN TA= .5 C (1 F) , ERROR IN RH= 5%
ERROR IN TC-TA IS 0,5 OR 1 C
REFERENCE FOR AN ST-27 WHICH IS EQUILIBRATED PROPERLY

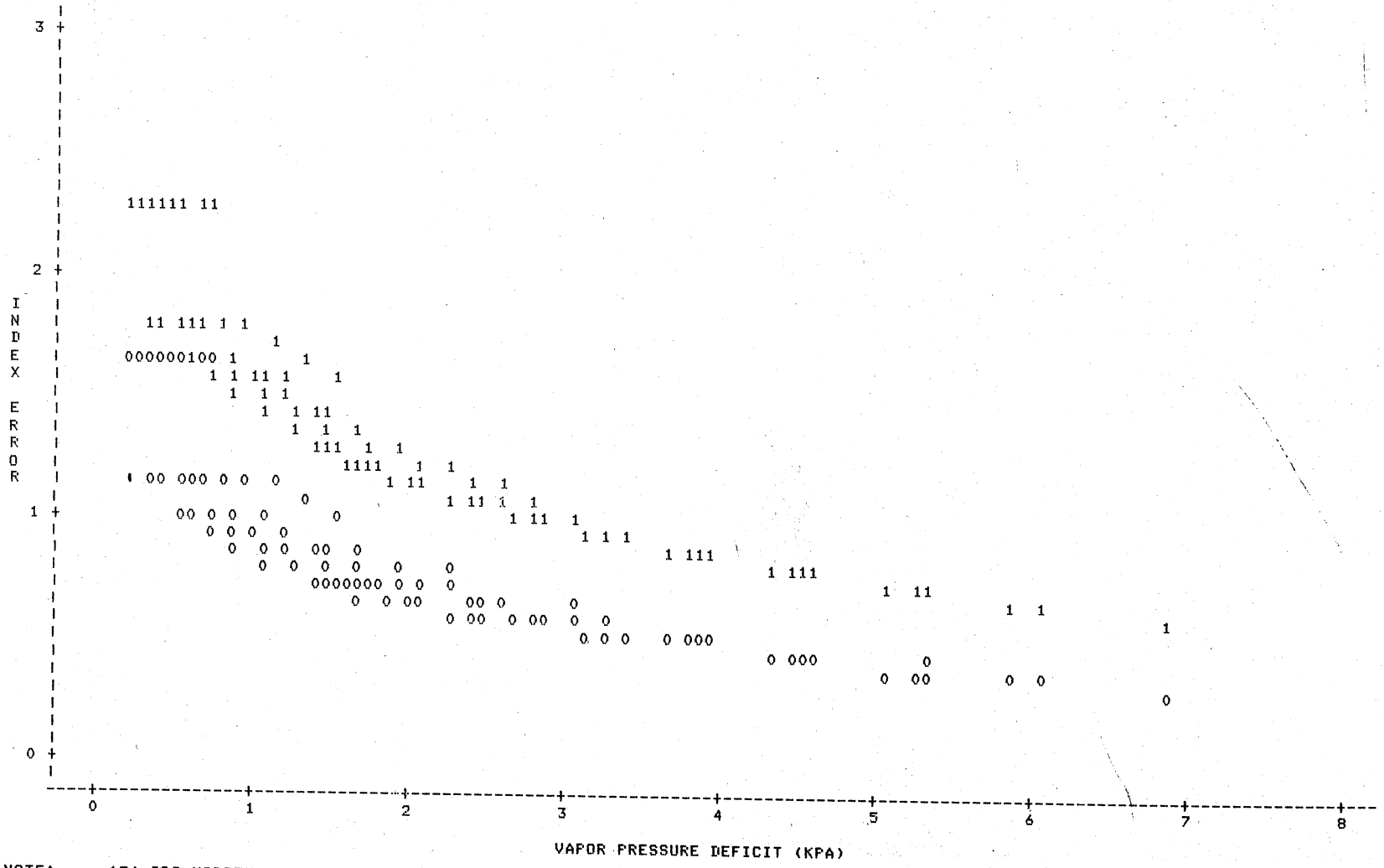
PLOT OF IERR*VPD SYMBOL IS VALUE OF DTE



NOTE: 174 OBS HIDDEN

ANALYSIS OF TURF INDEX ERRORS TRENDS IN PREDICTING AN INDEX OF 2
ERROR IN TA= .5 C (1 F) , ERROR IN RH= 5%
ERROR IN TC-TA IS 0.5 OR 1 C
REFERENCE FOR AN ST-27 WHICH IS EQUILIBRATED PROPERLY

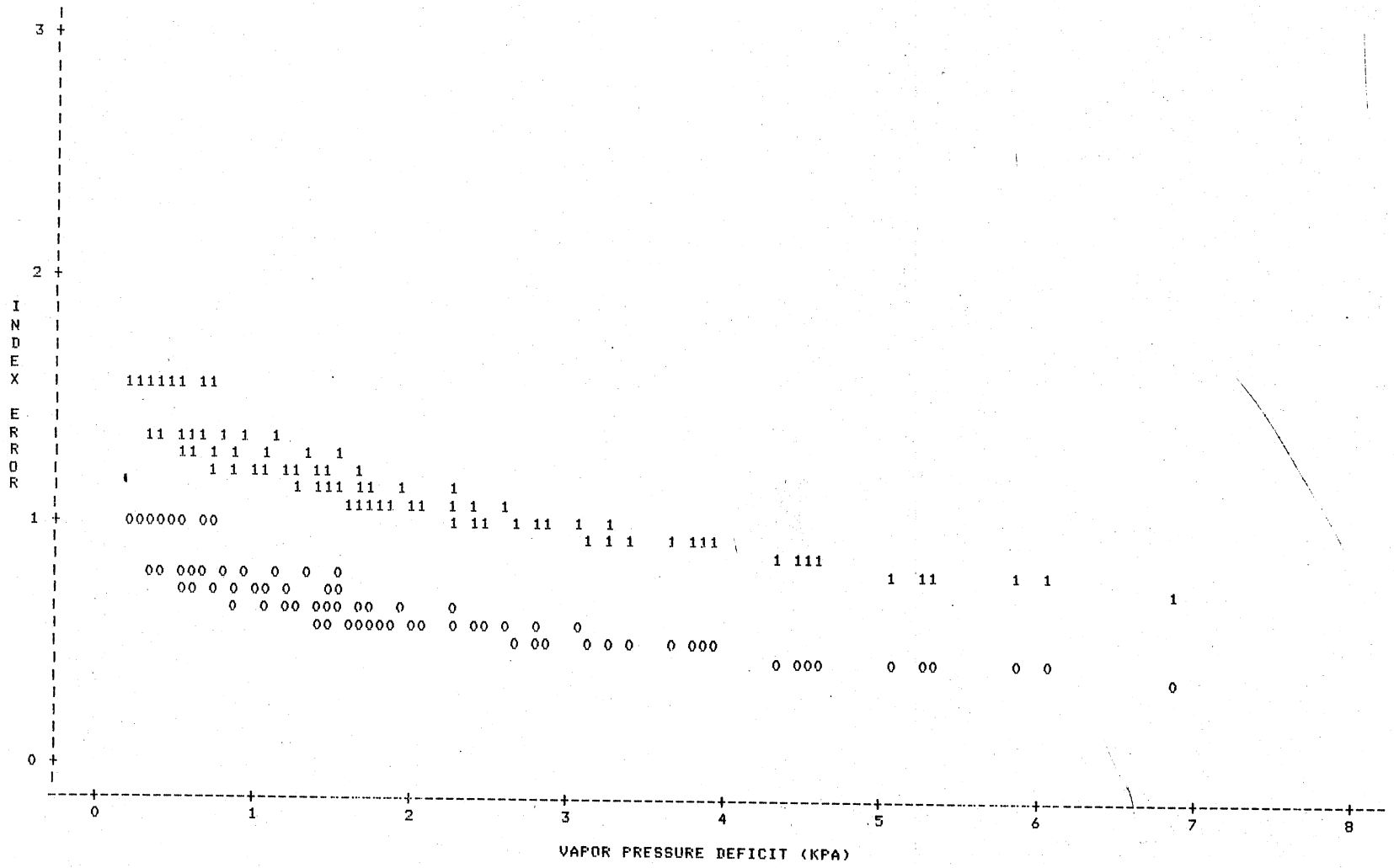
PLOT OF IERR*VPD SYMBOL IS VALUE OF DTE



NOTE: 174 OBS HIDDEN

ANALYSIS OF GRAPE INDEX ERRORS TRENDS IN PREDICTING AN INDEX OF 2
ERROR IN TA= .5 C (1 F) , ERROR IN RH= 5%
ERROR IN TC-TA IS 0.5 OR 1 C
REFERENCE FOR A SCHEDULER WHICH IS EQUILIBRATED PROPERLY

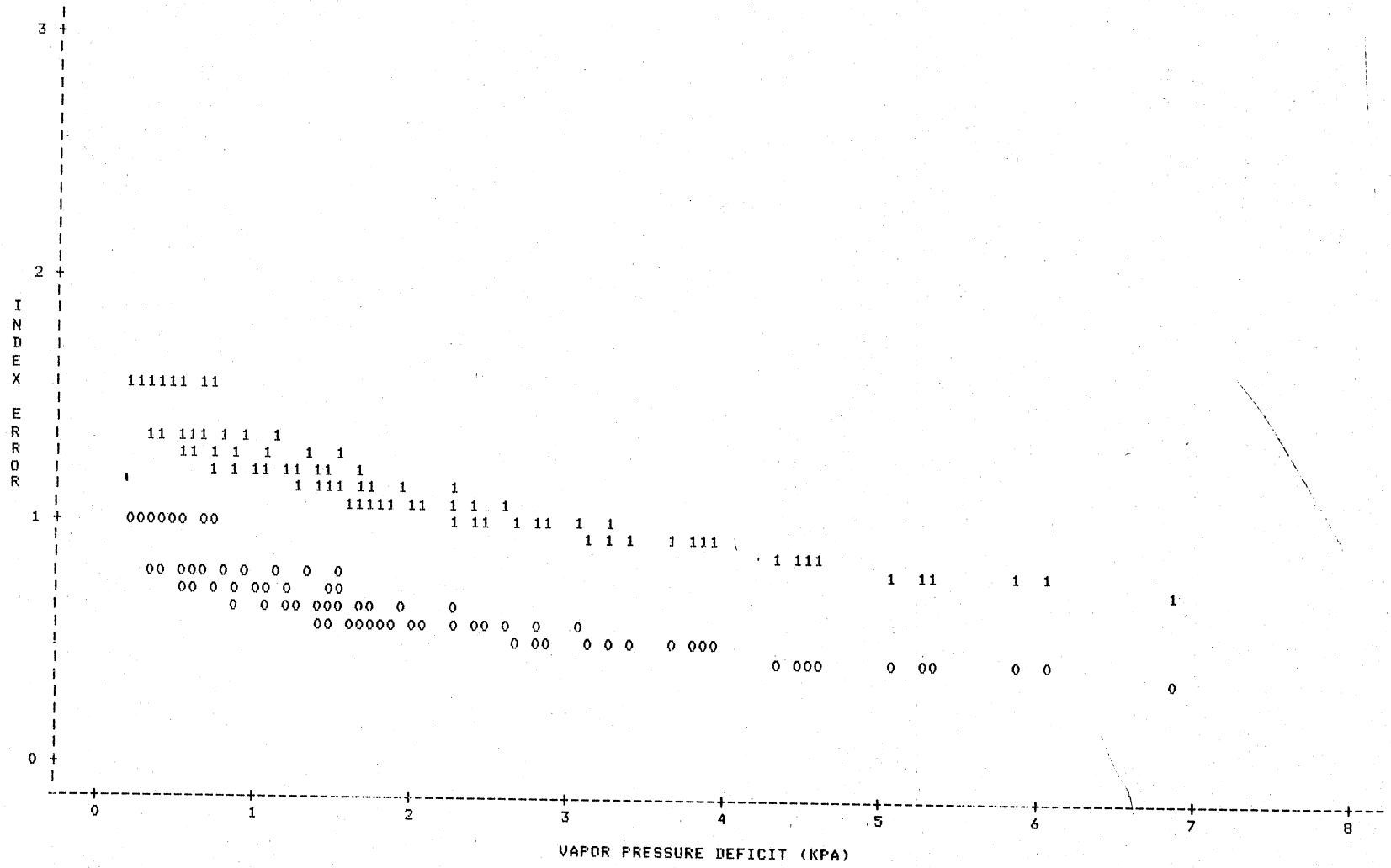
PLOT OF IERR*VPD SYMBOL IS VALUE OF DTE



NOTE: 174 OBS HIDDEN

ANALYSIS OF GRAPE INDEX ERRORS TRENDS IN PREDICTING AN INDEX OF 2
ERROR IN TA= .5 C (1 F) , ERROR IN RH= 5%
ERROR IN TC-TA IS 0.5 OR 1 C
REFERENCE FOR A SCHEDULER WHICH IS EQUILIBRATED PROPERLY

PLOT OF IERR*VPD SYMBOL IS VALUE OF DTE



NOTE: 174 OBS HIDDEN

The University of Georgia College of Agriculture

Experiment Stations • Georgia Station

EXPERIMENT, GEORGIA 30212

404/228-7272

DEPARTMENT OF AGRONOMY

February 25, 1987

Angle ≈ 30 - 35° from Horizontal

Dr. Bronson Gardner
Standard Oil Engineered Materials
6180 Cochran Road
Solon, OH 44139

Dear Dr. Gardner:

Enclosed is the final report concerning the "Infrared Thermometry Based Irrigation Scheduling of Turfgrass" project. The well-watered (lower) baselines for CWSI on the three warm-season grasses should be good approximations. Since these research plots are part of another continuing study, I will be collecting additional data in 1987. The 1987 data will concentrate on:

(a) gathering more ΔT data under well irrigated conditions under different solar radiation levels.

(b) as long as the time-domain reflectrometer works, we will gather ΔT versus VPD data at different soil moisture levels.

(c) on selected days, obtaining data under no transpiration (upper baseline) via reading on these grasses after root pruning.

We appreciate the financial support of Standard Oil. If we can be of assistance in the future, let me know.

Sincerely,

R N Carrow

R. N. Carrow
Associate Professor

RNC:n

encl.

AN EQUAL OPPORTUNITY / AFFIRMATIVE ACTION EMPLOYER
A Unit of the University System of Georgia

INFRARED THERMOMETRY BASED IRRIGATION SCHEDULING OF TURFGRASS: FINAL REPORT

Robert N. Carrow

OBJECTIVES

The three objectives of these investigations were:

1. To evaluate several canopy temperature based indices for their use in irrigation scheduling of warm-season grasses (Project I).
2. To develop baseline data for the indices that exhibit potential for irrigation scheduling (Project I).
3. To determine the influence of soil compaction on canopy temperature based irrigation scheduling (Project II).

RESULTS

Project I (Drought Study)

Data acquisition for these investigations was from June 11, 1986 through November 19, 1986. On October 6, all data through October 3 related to Projects I and II were submitted to Dr. Bronson Gardner. The remaining data (October 4 - Nov. 19) are attached to this project in Appendix A, B, and C.

It was our desire to obtain canopy temperature data on the three grass species in Project I under well-irrigated, slight stress, and moderate stress. This would allow development of the well-watered baselines for the Crop Water Stress Index (CWSI) indice. Also, we hoped to generate specific CWSI values related to a particular level of moisture stress as determined by soil moisture levels. Unfortunately, the time domain reflectrometry unit used to monitor soil moisture and to schedule irrigation events did not function properly - all units in the country are now being repaired and upgraded to prevent a reoccurrence of this problem. This hindered achievement of objective 2.

Canopy temperature data obtained on the first 1 to 3 days after rainfall or irrigation events can be used to generate the well-watered CWSI baseline for each grass (Project I). However, solar radiation also influences the CWSI by reducing canopy temperatures; thereby, causing lower ΔT values. Appendix D contains the data to calculate the well-watered baseline on days when solar radiation was at least 640 W/m^2. These days were selected by reviewing rainfall/irrigation periods and eliminating the days when ΔT values were very low. Thus, these data represent "incipient" stress conditions. When the grass plants were not under "incipient" stress, such as within 24 hours of a moderate rain, ΔT values were often low, regardless of light intensity. Figures 1, 2, and 3 contain the well-water baselines for bermudagrass, zoysiagrass, and centipedegrass. When I calculated these, the average ΔT for all three replications was used.

Appendix E contains data for well-watered conditions but on days with low solar radiation. Individual baselines are in Figures 1, 2, and 3. Three observations are noted: (a) The baseline for the low solar radiation situations is always less than the high radiation condition. (b) The greatest magnitude of error is at low VPD. Since only ΔT values above the well-watered, high solar radiation baseline represent stress on the plant, all readings below this line could be ignored. If the turfgrass comes under a moisture stress during a prolonged low solar radiation period, the low soil moisture should cause high ΔT even if solar radiation is low. For example, on 11-3-87, ΔT values were high but solar radiation was moderately low. (c) Since both VPD and solar radiation influence the

magnitude of ΔT, a response surface (response = ΔT) could be developed with different levels of VPD and solar radiation. An alternative would be a family of linear curves relating ΔT versus VPD but at several solar radiation levels (such as high, medium, low).

Additional data will be beneficial in refining the ΔT versus VPD relationship, especially to achieve a better correlation coefficient. Of particular interest would be ΔT values outside the VPD range of 1.0 to 3.0.

The baselines for the three warm-season grasses are reasonably similar but they do differ from the Kentucky bluegrass (cool-season grass) baseline (Figure 1, dashed line) found by Throssell et al (article attached, Appendix). This indicates that a potential exists for a common baseline to be used for these three warm-season grasses.

Project II (Compaction Study)

Since recreational sites are subjected to soil compaction, which can influence plant water relationships, we were interested in whether the lower CWSI baseline would be different under noncompacted versus compacted conditions. The data are in Appendix F and Figure 4.

Baselines were developed for non-compacted and compacted sites at high solar radiation (600 - 1000 W/m^2) and low solar radiation. There was no significant difference between the non-compacted and compacted situations at either light intensity. Comparison of the baselines in Figures 4 and 1 are of interest because both were on Tifway bermudagrass. The respective baselines are very similar.

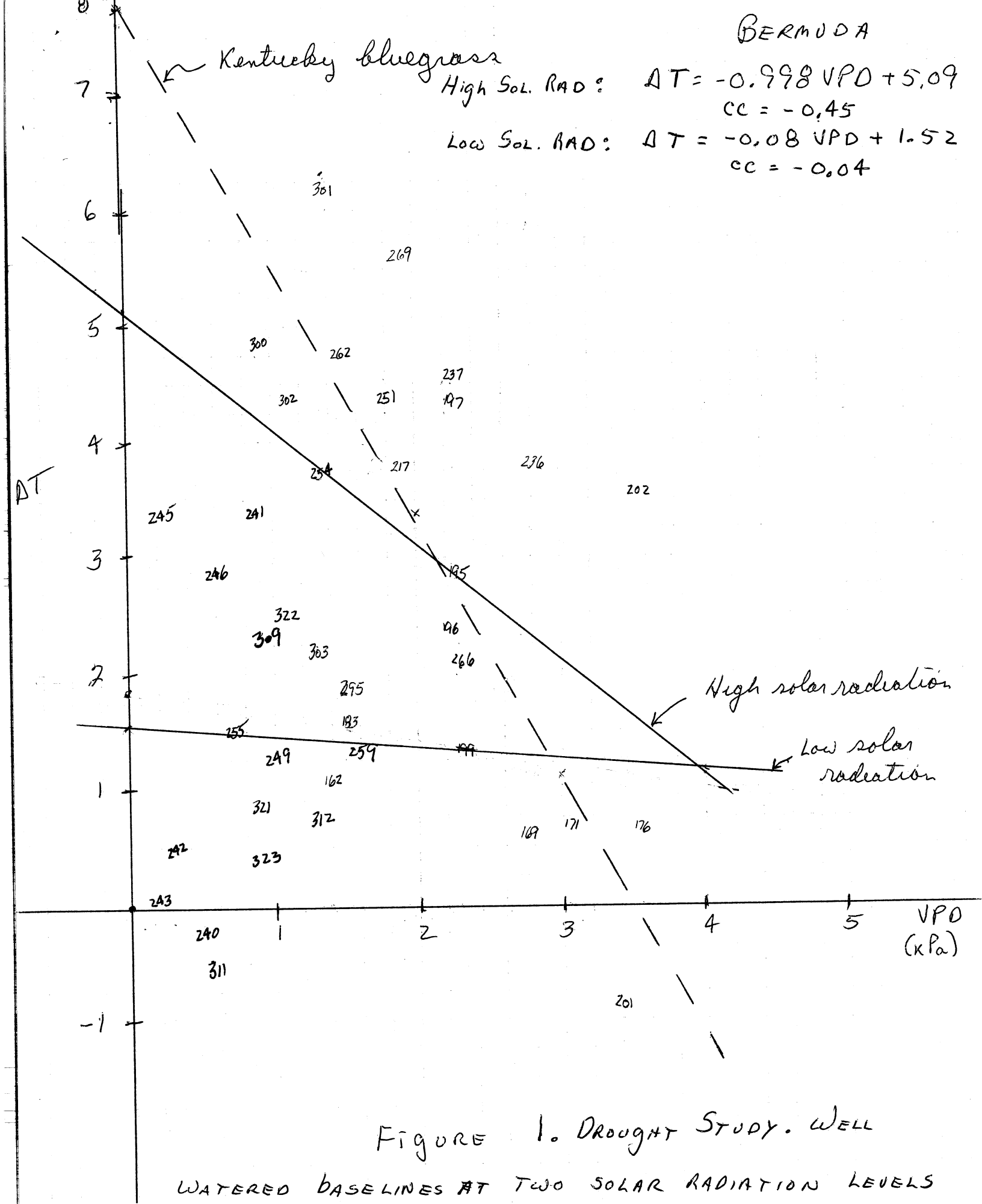


FIGURE 1. DROUGHT STUDY. WELL WATERED BASELINES AT TWO SOLAR RADIATION LEVELS FOR BERMUDA. 1986

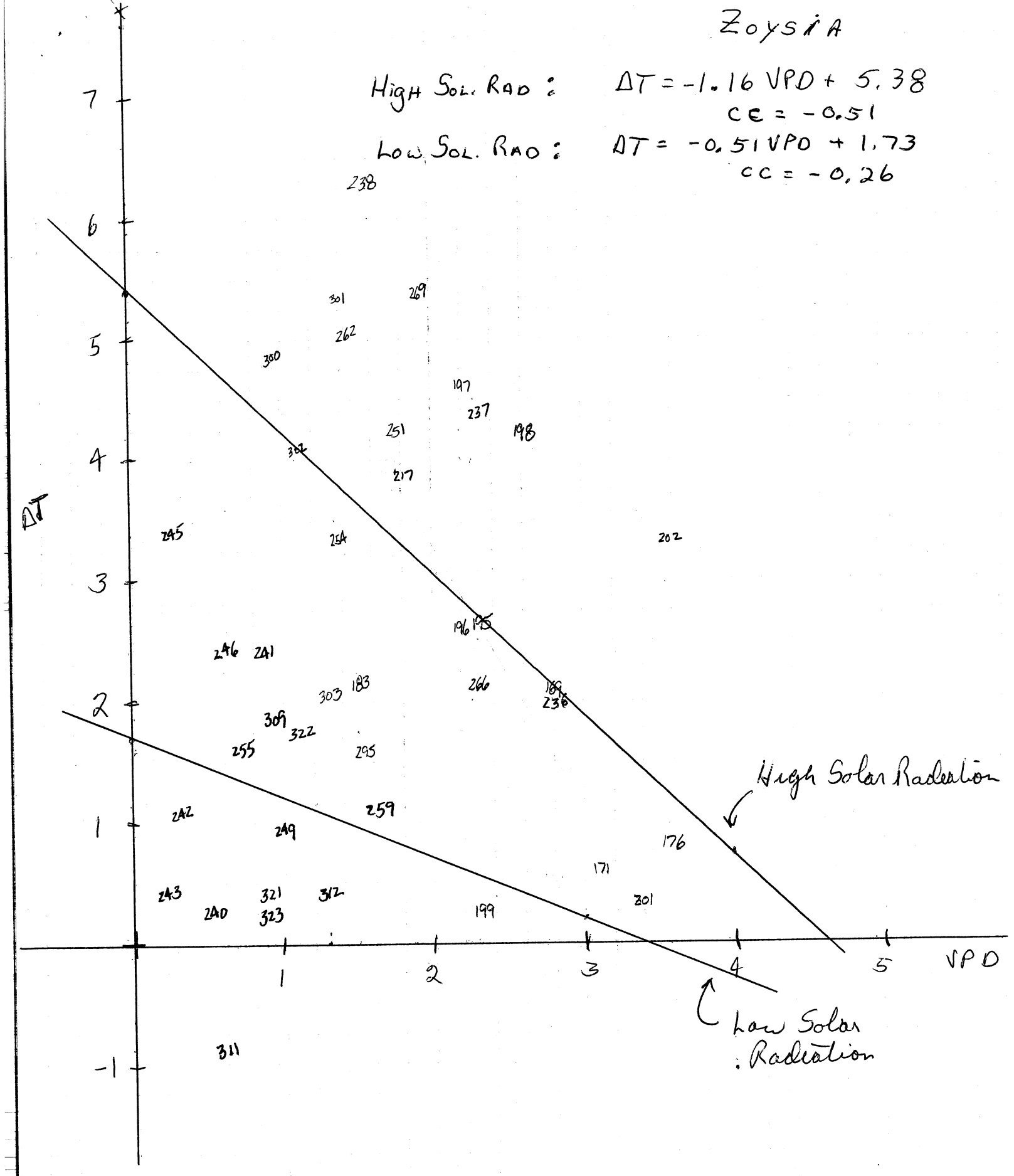


FIGURE 2. DROUGHT STUDY. WELL WATERED BASELINES AT TWO SOLAR RADIATION LEVELS FOR ZOYSIA, 1986.

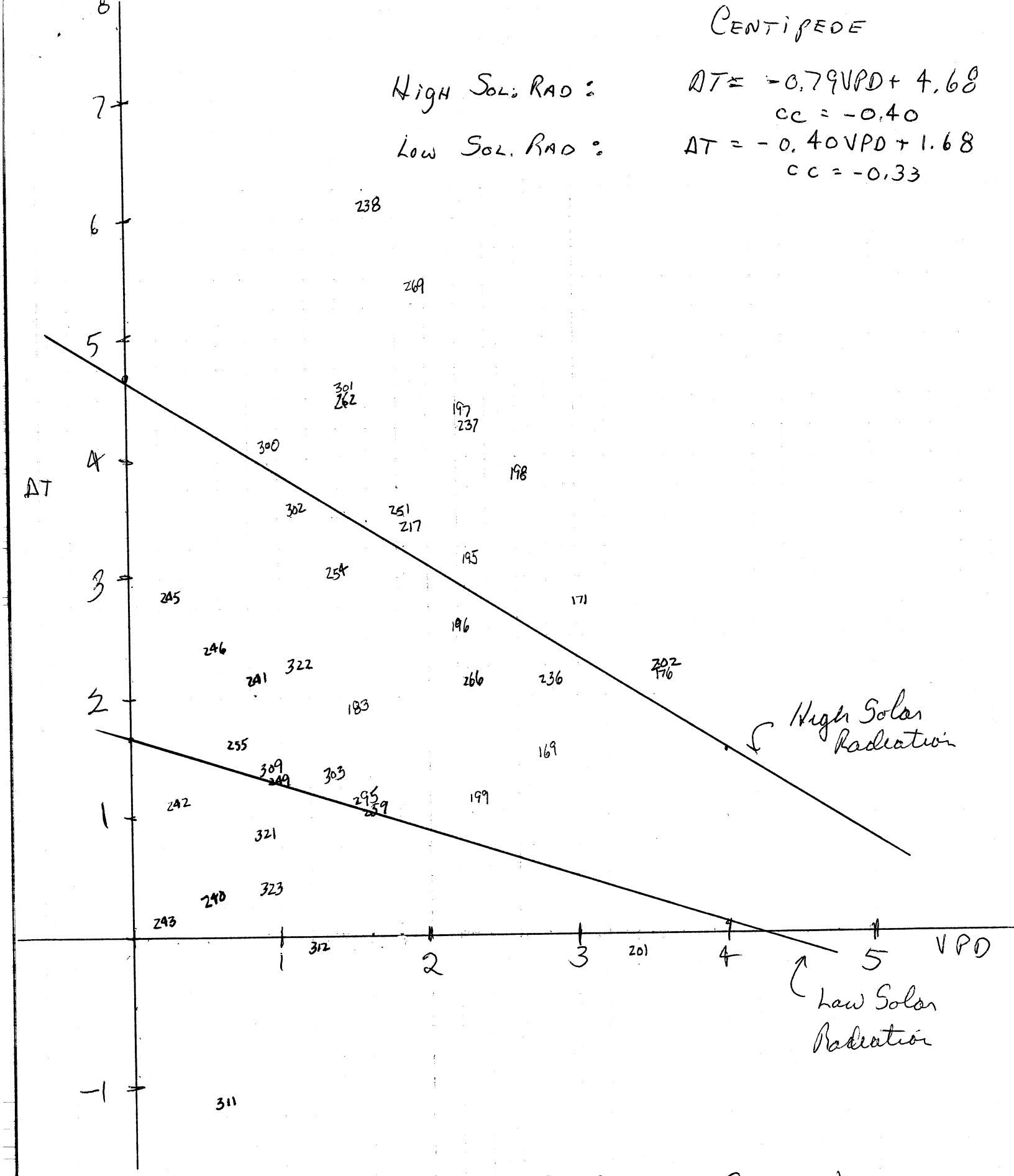


FIGURE 3. DROUGHT STUDY. WELL WATERED BASELINES AT TWO SOLAR RADIATION LEVELS FOR CENTIPEDE. 1986

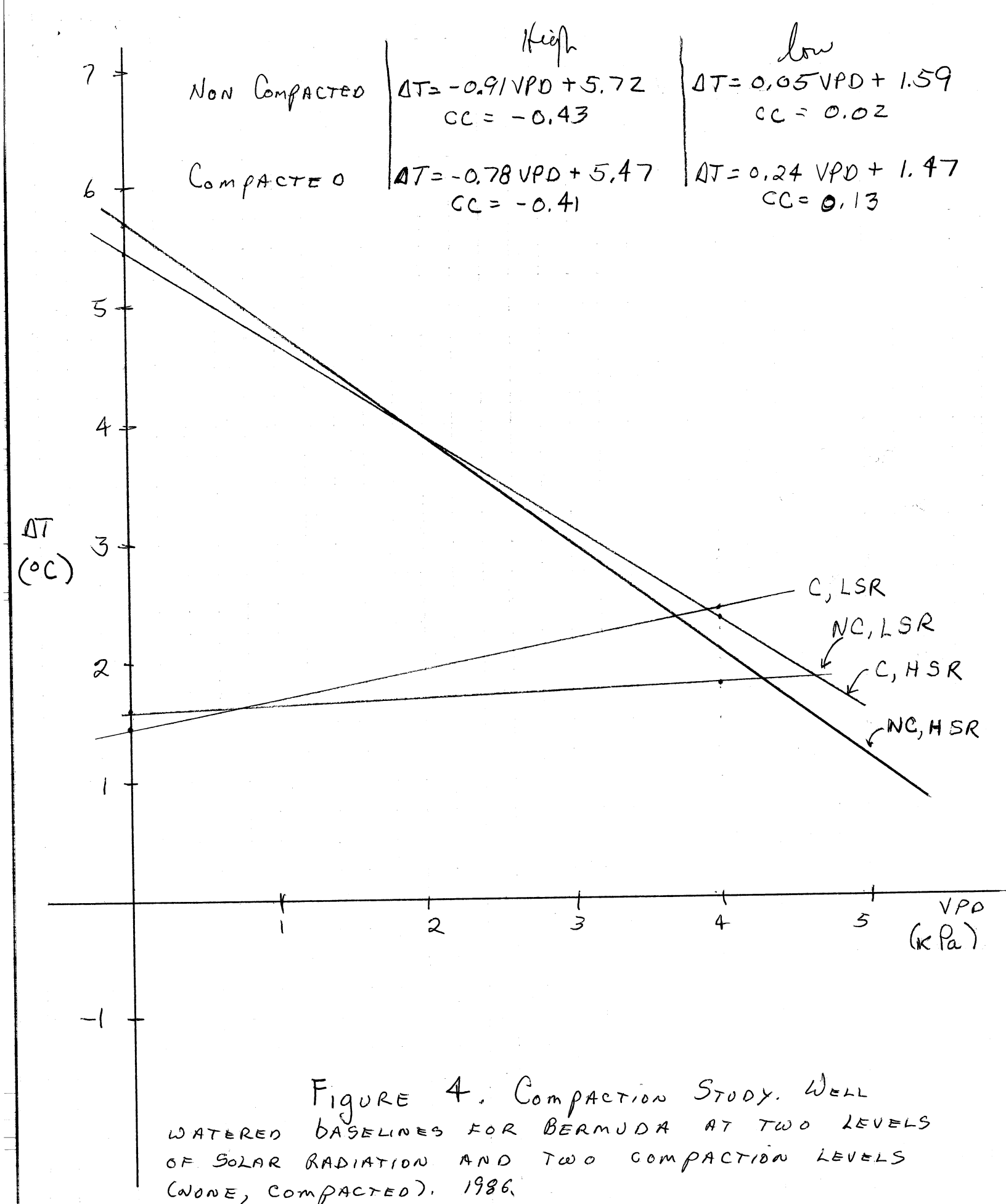


FIGURE 4. COMPACTION STUDY. WELL WATERED BASELINES FOR BERMUDA AT TWO LEVELS OF SOLAR RADIATION AND TWO COMPACTION LEVELS (NONE, COMPACTED). 1986.

APPENDIX A-1986

DROUGHT STUDY (PROJECT I)
The days with a (✓) can be considered well watered and be used for baseline data. See Note # 2

Date	Computer I.D. Notation	Air Temp °C DB	Air Temp °C WB	VPD kPa	Sol Rad W/m^2	
10-22-86	295	22.2	15.0	1.54	640	✓
10-27	300	19.4	14.4	0.94	691	✓
10-28	301	22.2	15.6	1.43	687	✓
10-29	302	21.1	15.6	1.09	627	✓
10-30	303	22.2	15.6	1.33	882	✓
10-31	304	21.1	15.6	1.09	614	
11-3	308	21.1	16.7	0.89	473	
11-4	309	22.2	17.8	0.93	477	
11-5	310	19.4	16.7	0.53	640	
11-6	311	23.9	20.0	0.59	422	
11-7	312	28.3	23.3	1.27	487	
11-17	321	23.3	19.4	0.89	365	
11-18	322	24.4	20.0	1.10	578	
11-19	323	16.1	10.6	0.93	286	

Note #1: All weather data is for the time that canopy temperatures measurements were made — 12:30 to 2:00 pm.

Note #2: Use ΔT from Plot numbers 1-3; 10-12; 19-21 for bermuda, zoysia, centipede, respectively.

APPENDIX B-1986

DROUGHT STUDY (PROJECT I)

Canopy Temperature Data (°C)

Date		10-22-86			10-27-86			10-28-86			10-29-86		
Treatment ↓ REP		#1	#2	Av.	#1	#2	Av	#1	#2	Av	#1	#2	Av
WELL WATER	1 BERMUDA	23.8	23.9	23.85	24.9	24.2	24.55	29.9	29.8	29.85	26.4	25.5	25.95
	2	24.4	23.7	24.05	24.0	24.0	24.00	26.4	26.5	26.45	24.5	24.4	24.45
	3	24.0	24.8	24.40	24.2	24.0	24.10	27.3	30.4	28.85	25.7	25.8	25.75
	4												
	5												
	6												
	7												
	8												
	9												
	10	23.3	24.2	23.75	24.0	24.4	24.20	27.3	27.9	27.60	25.0	25.7	25.35
WELL WATER	11 ZOYSIA	22.4	24.0	23.20	24.7	24.3	24.50	28.5	28.1	28.30	25.4	25.4	25.40
	12	24.7	24.3	24.50	24.0	24.7	24.35	26.2	26.8	26.50	24.7	24.7	24.70
	13												
	14												
	15												
	16												
	17												
	18												
WELL WATER	19 CENTIPEDE	24.0	23.6	23.80	23.2	23.4	23.30	26.2	26.6	26.40	24.6	24.1	24.35
	20	23.2	23.5	23.35	23.5	23.9	23.70	26.5	26.8	26.65	24.5	24.3	24.40
	21	22.9	22.4	22.65	24.2	23.6	23.90	26.3	28.1	27.20	24.1	25.1	24.60
	22												
	23												
	24												
	25												
	26												
	27												
		D.b = 72°F W.b = 59°F RH = 46% sol. 640			D.b. 67°F W.b 58°F RH = 64% Sol 691			D.b = 72°F W.b = 60°F RH = 50% Sol 687			D.b. 70°F W.b 60°F RH = 56% 627		

Date	10-30-86			10-31-86			11-3-86			11-4-86		
Treatment + Rep	#1	#2	Av.	#1	#2	Av	#1	#2	Av	#1	#2	Av
1	24.0	24.8	24.40	20.0	21.2	20.60	29.5	28.7	29.10	24.5	24.9	24.70
2	23.7	25.7	24.70	20.5	21.6	21.05	28.6	27.6	28.10	24.5	24.0	24.25
3	24.3	23.9	24.10	21.8	22.2	22.00	28.0	28.2	28.10	24.5	24.5	24.50
4												
5												
6												
7												
8												
9												
10	23.8	24.8	24.30	21.4	21.0	21.20	28.6	28.5	28.55	24.3	24.3	24.30
11	24.8	25.3	25.05	22.0	22.0	22.00	28.7	27.6	28.15	24.5	24.1	24.30
12	23.2	23.4	23.30	20.3	20.8	20.55	27.7	26.1	26.90	24.1	23.5	23.80
13												
14												
15												
16												
17												
18												
19	23.6	24.0	23.80	20.4	20.4	20.40	27.6	26.3	26.95	23.3	23.4	23.35
20	22.8	22.6	22.70	21.0	21.0	21.00	28.0	27.2	27.60	23.7	23.4	23.55
21	24.8	24.1	24.45	21.2	21.4	21.30	26.2	27.8	27.00	24.1	24.1	24.10
22												
23												
24												
25												
26												
27												
	D.b = 72 W.b = 60 RH = 50% Sol. 882			D.b = 70°F W.b = 60°F RH = 56% Sol 614			D.b = 70 W.b = 62 RH = 64% Sol 473			D.b = 72 W.b = 64 RH = 66% Sol. 477		

Date / Treatment + Rep	11-5-86			11-6-86			11-7-86			11-17-86		
	#1	#2	Av.	#1	#2	Av	#1	#2	Av	#1	#2	Av
1	17.7	17.9	17.80	23.3	24.5	23.90	29.6	29.1	29.35	24.4	24.3	24.35
2	17.8	17.9	17.85	22.8	22.8	22.80	28.2	28.6	28.40	24.2	23.9	24.05
3	17.9	17.9	17.90	23.2	23.7	23.45	29.0	29.8	29.40	24.0	24.2	24.10
4												
5												
6												
7												
8												
9												
10	18.3	18.1	18.20	23.1	23.0	23.05	28.9	29.1	29.00	23.8	23.5	23.65
11	18.2	18.5	18.35	23.3	23.5	23.40	28.8	28.9	28.85	23.6	23.2	23.40
12	18.1	17.8	17.95	23.0	22.8	22.90	28.2	28.6	28.40	24.4	24.0	24.20
13												
14												
15												
16												
17												
18												
19	17.9	17.9	17.90	22.4	22.3	22.35	28.0	28.2	28.10	24.7	24.2	24.45
20	18.1	18.1	18.10	22.9	22.8	22.85	28.1	28.5	28.30	23.2	23.0	23.10
21	18.3	18.2	18.25	22.8	23.3	23.05	28.0	28.6	28.30	25.0	24.6	24.80
22												
23												
24												
25												
26												
27												

D.b. 67°
W.b. 62
RH = 76%
Sol. 640

D.b = 75°
W.b = 68°
R.H - 71%
Sol. 422

Db. 83°F
W.b = 74°F
RH = 66%
Sol. 487

D6 = 74
W.b = 67
RH =
Sol - 365

Date	11-18-86			11-19-86								
Treatment + REP	#1	#2	Av.	#1	#2	Av	#1	#2	Av.	#1	#2	Av
1	26.7	27.2	26.95	16.4	16.7	16.55						
2	26.6	25.8	26.20	16.3	16.5	16.40						
3	26.9	28.2	27.55	16.8	16.4	16.60						
4												
5												
6												
7												
8												
9												
10	26.5	26.4	26.45	16.4	16.5	16.45						
11	26.9	26.3	26.60	16.4	16.3	16.35						
12	25.5	25.3	25.40	16.0	16.5	16.25						
13												
14												
15												
16												
17												
18												
19	26.4	26.0	26.20	16.7	16.3	16.50						
20	27.5	26.3	27.00	16.7	16.5	16.60						
21	26.9	26.7	26.80	16.9	16.2	16.55						
22												
23												
24												
25												
26												
27												

Db 76°
Wb 68
Sol 578

Db = 61°F
Wb = 51°F
Sol - 286

APPENDIX C - 1986

Drought Study
Project I

Date	Rainfall or Irrigation on all Plots
10-10-86	1.02
10-11-86	0.50
10-12-86	0.50
10-13-86	0.12
10-14-86	1.93
10-21-86	1.00
10-25-86	0.50
10-26-86	0.45
11-1-86	0.05
11-12-86	0.27
11-15-86	0.25
11-17-86	0.65

Well Watered Baseline Data : High Solar Radiation
Drought Study (Project I)

APPENDIX D-1986

DATE	DAY	VPD kPa	SOL RAD w/m^2	AIR TEMP DB (°C)	ΔT (°C) by GRASS		
					BERM	ZOYSIA	CENTI
6-11	162	1.37	920	27.2	1.02	—	—
6-18	169	2.75	1012	32.8	0.60	2.13	1.53
6-20	171	3.03	795	33.3	0.70	0.57	2.70
6-26	176	3.55	907	35.0	0.70	0.93	2.23
7-2	183	1.50	1035	29.4	1.60	2.20	1.93
7-14	195	2.27	1005	32.2	2.92	2.67	3.20
7-15	196	2.18	997	31.1	2.38	2.63	2.58
7-16	197	2.18	1000	32.8	4.32	4.63	4.40
7-17	198	2.60	995	32.8	[illegible]	4.20	3.90
7-18	199	2.31	1010	34.4	1.28	0.25	1.13
7-20	201	3.40	998	35.0	-0.90	0.28	-0.15
7-21	202	3.54	1015	35.0	3.55	3.32	2.20
8-5	217	1.83	823	30.0	3.88	3.80	3.47
8-24	236	2.78	670	33.3	3.82	2.03	2.20
8-25	237	2.28	835	32.2	4.53	4.38	4.40
8-26	238	1.56	925	30.0	[illegible]	6.30	6.13
9-8	251	1.77	710	27.5	4.40	4.20	3.63
9-11	254	1.35	1034	28.9	3.75	3.40	3.03
9-19	262	1.43	776	27.8	4.77	5.02	4.50
9-23	266	2.27	802	32.2	2.15	2.08	2.15
9-26	269	1.92	796	31.1	5.70	5.35	5.48
10-22	295	1.54	640	22.2	1.90	1.62	1.07
10-27	300	0.94	691	19.4	4.82	4.95	4.17
10-28	301	1.43	687	22.2	6.18	5.27	4.55
10-29	302	1.09	627	21.1	4.28	4.05	3.35
10-30	303	1.33	882	22.2	2.20	2.02	1.43

	cc	Intercept	Slope	Equation
BERMUDA	-0.45	5.09	-0.998	$\Delta T = -0.998\,VPD + 5.09$
ZOYSIA	-0.51	5.38	-1.16	$\Delta T = -1.16\,VPD + 5.38$
CENTIPEDE	-0.40	4.68	-0.79	$\Delta T = -0.79\,VPD + 4.68$

Well Watered Baseline Data : Low Solar Radiation

Drought Study (Project I)

APPENDIX E-1986

DATE	DAY	VPD KPa	SOL RAD W/m^2	AIR TEMP DB (°C)	ΔT (°C) by GRASS		
					BERM	ZOYSIA	CENTI
~~6-30~~	~~181~~	~~1.76~~	~~675~~	~~29.4~~	~~3.77~~	~~3.97~~	~~5.97~~
~~7-10~~	~~191~~	~~2.57~~	~~654~~	~~32.7~~	~~1.90~~	~~3.53~~	~~1.45~~
~~8-23~~	~~235~~	~~2.18~~	~~268~~	~~31.4~~	~~8.08~~	~~5.45~~	~~6.00~~
8-28	240	0.51	108	23.9	-0.25	0.25	0.27
8-29	241	0.84	318	18.9	3.42	2.47	2.17
8-30	242	0.29	240	15.0	0.45	1.03	1.08
8-31	243	0.20	183	18.3	0.02	0.42	0.12
9-2	245	0.25	251	22.2	3.40	3.43	2.85
9-3	246	0.57	380	25.6	2.88	2.47	2.47
9-6	249	0.99	400	26.7	1.25	0.97	1.30
9-12	255	0.72	603	26.7	1.50	1.62	1.62
9-16	259	1.62	322	29.4	1.27	1.05	1.03
~~11-3~~	~~308~~	~~0.82~~	~~473~~	~~22.1~~	~~7.33~~	~~6.72~~	~~6.08~~
11-4	309	0.93	477	22.2	2.28	1.93	1.47
11-6	311	0.59	422	23.9	-0.52	-0.78	-1.15
11-7	312	1.27	487	28.3	0.75	0.45	-0.01
11-17	321	0.89	365	23.3	0.87	0.45	0.82
11-18	322	1.10	578	24.4	2.50	1.75	2.27
11-19	323	0.93	286	16.1	0.40	0.25	0.45

	CC	Intercept	Slope	Equation
BERMUDA	-0.04	1.52	-0.08	$\Delta T = -0.08\ VPD + 1.52$
ZOYSIA	-0.26	1.73	-0.51	$\Delta T = -0.51\ VPD + 1.73$
CENTIPEDE	-0.33	1.68	-0.40	$\Delta T = -0.40\ VPD + 1.68$

Compaction Study on Bermudagrass
Project II

APPENDIX F - 1986

Date	Day	VPD kPa	SOL RAD w/m²	AIR TEMP DB °C	Tc NC	ΔT NC	Tc C	ΔT C	
8-22	234	2.14	880	30.6	38.7	8.1	38.1	7.5	
8-23	235	2.18	680	31.1	34.1	3.0	35.0	3.9	✓*
8-24	236	2.78	670	33.3	37.5	4.2	37.3	4.0	✓*
8-25	237	2.28	835	32.2	36.0	3.8	35.8	3.6	✓*
8-26	238	1.56	925	30.0	36.6	6.6	36.6	6.6	
8-28	240	0.51	108	23.9	23.3	-0.6	23.2	-0.7	✓
8-29	241	0.84	318	18.9	19.3	0.4	19.8	0.9	✓
8-30	242	0.29	240	15.0	15.8	0.8	16.1	1.1	
8-31	243	0.20	133	18.3	18.5	0.2	18.3	0	✓
9-1	244	0	159	20.0	21.9	1.9	21.7	1.7	✓
9-2	245	0.25	251	22.2	25.9	3.7	25.6	3.4	✓
9-3	246	0.57	380	25.6	27.4	1.8	27.8	2.2	✓
9-4	247	1.17	666	27.8	31.1	3.3	30.9	3.1	✓*
9-5	248	1.76	396	29.4	27.5	-1.9	27.6	-1.8	✓
9-6	249	0.99	400	26.7	28.3	1.6	28.5	1.8	✓
9-7	250	1.43	620	27.8	33.0	5.2	33.1	5.3	✓*
9-9	252	0.92	525	24.4	30.5	6.1	30.3	5.9	
9-11	254	1.35	1034	28.9	31.4	2.5	31.4	2.5	
9-16	259	1.62	322	29.4	30.6	1.2	30.9	1.5	
9-18	261	0.42	285	20.6	23.0	2.4	22.5	1.9	✓
9-19	262	1.43	776	27.8	33.7	5.9	33.3	5.5	✓*
9-23	266	2.27	802	32.2	35.1	2.9	35.4	3.2	
9-26	269	1.92	796	31.1	37.6	6.5	37.9	6.8	
9-29	272	1.38	820	29.4	35.5	6.1	35.7	6.3	
~~9-30~~	~~273~~	—	—	~~3~~	~~32.8~~	—	~~34.4~~	—	
10-1	274	1.66	825	31.1	33.9	4.8	36.0	4.9	
10-3	276	2.40	780	32.2	34.4	2.2	34.4	2.2	✓*

✓ = well watered, low solar radiation

✓* = well watered, high solar radiation

12 April 1988

TURF Correction

IF Doy $\leq$ 91

A = Current Intercept
Max = Current Max

$$A = (A-6) + 0.0671 * Doy$$
$$Max = (Max-6) + 0.0671 * Doy$$

IF Doy > 91 and Doy L 274 — No change

IF Doy > 274

$$A = A - 0.0654(Doy-274)$$
$$Max = Max - 0.0654(Doy-274)$$

$7.0 - 1.9 * VPD$ Max = 13.0

ST27

TURF Adjustment

	Intercept	Slope	Max
January	2.0	-1.9	8
Feb	3.3	-1.9	9
March	4.6	-1.9	11
April	6.0	-1.9	12
May	7.0	-1.9	13
June	7.0	-1.9	13
July	7.0	-1.9	13
Aug.	7.0	-1.9	13
Sept	6.0	-1.9	12
Oct	4.6	-1.9	11
Nov.	3.3	-1.9	9
Dec.	2.0	-1.9	8

CLV 193-C

SHEET NO. ____ OF ____

FILE ____

SUBJECT 15 Minute TA Variation

DATE 1 June 1988

BY BJ

Wind

1	~~Start~~	84.3			86.1 no wind
2		83.9		1:45	86.0
3		83.8			85.6
4		83.6			85.5
5		83.8			85.4
6		83.5			84.3
7		83.7 no wind		2:00	~~83.6~~
8		83.5			~~83.5~~
9		83.3			83.4
10	30 Sec.	83.1			~~83.5~~ no wind
11		83.3			83.8
12		82.9			83.7
13		83.3			83.8
14		83.3		2:15	83.7
15	45 Sec.	84.1			83.8 no wind
16		84.5 gust			84.2
17		84.6			84.6
18		84.4			84.9
19		84.8			85.1
20	1 min	84.7 0 wind			85.5
21		84.4		2:30	~~85.6~~
22		~~84.6~~			85.7
23		84.7			~~85.6~~
24		85.0			85.4
25		~~84.8~~			85.0
26	1:15	84.7 gust			85.1
27		85.5		2:45	~~84.9~~
28		~~85.4~~			84.6 no wind
29		~~84.8~~			84.9
30		84.9			85.2
31		~~85.0~~			85.9 gust
32		85.2			~~86.0~~
33		85.8		3:00	~~85.7~~ 3 minute
34	1:30	86.3			85.5 3 minute
35		86.6			85.3
36		86.8			84.8
37		86.6 5-6 mph			~~84.5~~
38		86.2			85.3

CLV 193-C

SHEET NO. _____ OF _____

FILE _____

SUBJECT _____

DATE _____

BY _____

3:00	85.3		85.8		85.2			
	~~84.8~~		84.2		~~85.0~~			
	84.5		85.5		84.9			
	85.3		~~84.9~~		~~85.1~~			
3:15	86.0		84.7		85.4			
	86.1		4:45	84.9	6:15	86.3		
	~~86.3~~			84.5		85.8		
	86.4			84.3		~~85.1~~		
	85.9			~~84.7~~		~~85.4~~		
	85.2		5:00	84.9		84.6		
	~~85.6~~			85.1		~~84.8~~		
3:30	85.6			85.1	6:30	84.8		
	86.0			85.5		84.7		
	86.4			85.4		84.8		
	~~85.7~~			84.8		84.9		
3:45	85.6		5:15	84.9		84.2		
	85.7			85.3		83.5		
	86.0			85.4	6:45	83.6		
	86.3			84.8		83.0		
	~~86.2~~			84.9		82.5		
	~~85.8~~			85.3		82.9		
4:00	84.2			85.5		83.6		
	84.8			85.4		84.5		
	85.2		5:30	85.6	7:00	~~84.9~~		
	~~85.0~~			85.4		85.2		
	~~85.3~~			~~86.0~~		85.4		
	85.0			~~86.0~~		85.3		
	84.8			85.5		~~85.0~~		
4:15	~~85.1~~			85.0		85.1		
	85.2		5:45	~~85.3~~		85.5		
	85.0			~~85.2~~		85.5		
	85.5			~~85.0~~		85.6		
	~~85.7~~			84.7		85.7		
	85.9			~~84.7~~		86.2		
4:30	85.5			84.8		85.9		
	85.3		4:02	84.7	7:30	~~85.4~~		
	85.6			85.1		84.8		

CLV 193-C

SHEET NO. _____ OF _____

FILE _____

SUBJECT _____

DATE _____

BY _____

1			84.7			9:00	84.1			85.4
2			85.1				84.1			85.5
3	7:45		84.7				84.2			85.6
4			84.5				84.0			86.0
5			84.5				Restart			86.2
6			83.8			9:30	84.4			86.0
7			83.2				85.0			85.8
8			83.1				85.5			85.8
9		8:00	83.2				85.3			85.7
10			83.2				85.1			85.4
11			83.4				84.9		11:00	85.4
12			83.8				84.9			85.5
13			83.8				85.1			85.8
14			84.2				85.2			85.0
15			83.7				85.2			84.8
16			83.3				85.1			85.4
17			83.3				85.4			86.1
18			83.2				85.6			86.4
19			83.2				85.5			86.5
20			83.7				85.7			86.3
21			84.2				85.5			86.3
22			84.2				85.4			86.0
23			84.1			10:00	85.5			86.1
24			84.0				85.5			86.0
25			84.0				85.3			85.9
26			84.0				85.1		11:30	85.8
27			84.2				85.3			85.1
28			83.7				85.7			85.0
29			83.4				85.3			85.1
30			83.3				85.3			85.2
31			83.2				85.3			84.6
32			83.4				85.2			84.5
33			83.7				85.2			84.9
34			84.1				84.5			85.1
35			83.6				84.6			85.2
36			83.1				84.2			84.8
37			82.9				84.9			84.6
38			83.3				85.2			

CLV 193-C

SHEET NO. _____ OF _____

FILE _____

SUBJECT _____

DATE _____

BY _____

			84.5				84.9				84.9	
			84.5				84.7				84.8	
			84.7				84.8				84.7	
		12:00	84.7				85.0				84.6	
			84.7				84.8				84.7	
			84.9				84.8				84.7	
			84.9				83.8				84.9	
			85.2				83.6				84.8	
			85.4				83.9				84.8	
			84.9				84.3				84.5	
			84.5			13:30	84.4				84.6	
			84.5				84.5				84.8	
			84.6				84.6				85.0	
			84.5				84.5			15:00	84.9	
			84.5				84.8					
		12:30	84.6				84.8					
			84.6				84.6					
			84.5				84.5					
			84.7				84.9					
			84.6				85.0					
			84.5				84.5					
			84.7			14:00	84.2					
			84.7				84.1					
			84.7				83.9					
			84.7				84.0					
			85.0				84.1					
			85.1				84.3					
			85.1				84.3					
		13:00	85.4				84.4					
			85.1				84.1					
			84.6				84.3					
			84.9				84.3					
			85.0				84.4					
			85.2				84.6					
			85.2				84.9					
							84.9					
						14:30	85.0					

CLV 193-C

SUBJECT

SHEET NO. OF

FILE

DATE 5/31/88

BY CGS

Same as standard indoors

#252 – #

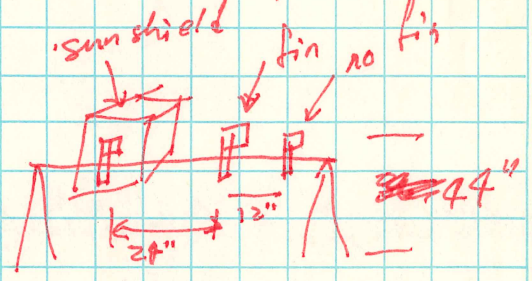
Reads low 0.2–0.3 compared to standard indoors

Mod'd Unit # 670 Unmod # 495

Time	T_{AIR}	$T_{AIR,STD}$	T_{AIR}
inside 0	73.2		73.2
1:30	83.1		82.9
~~3:00~~	~~84.4~~	~~83~~	~~84.2~~
3:45	80.4	83.1	80.7
4:15	81.8	83.0	82.0
4:45	82.6	84.2	82.7
5:30	82.8	85.3	83.2
6:00	83.6	85.7	83.5
6:30	83.6	86.0	83.8
7:10	83.6	85.6	83.7
7:40	83.3	84.9	83.4
8:10	83.5	85.5	83.5
8:40	83.4	84.3	83.3
9:10	83.4	84.5	83.2
9:40	83.4	84.7	83.6
10:40	83.3	84.7	83.8
11:10	82.7	83.7	82.8
11:40	83.5	84.1	84.0
12:10	82.9	84.1	82.5
12:40	82.6	84.1	82.5
13:10	82.7	84.1	82.6
13:40	82.6	83.2	82.6
14:10	83.0	84.0	83.1
14:40	82.9	84.4	83.0
15:10	83.6	84.5	83.4
15:40	83.2	83.5	82.9
16:15	82.4	83.9	82.0
16:45	83.2	83.9	83.2
17:45	82.3	83.6	82.4
18:45	82.2	83.2	82.4
19:45	82.6	83.7	82.4
22:30	84.1	84.4	84.1
24:00	83.9	84.4	84.2
26:00	83.8	84.9	84.0
28.00	82.4	83.6	82.1

NOTES

Breezy



Sun 82

Sun 82

CLV 193-C

SUBJECT

Pointed @ Cement IR: 95°

Pointed @ Sky / Woods IR: 69°

SHEET NO. 2 OF

FILE

DATE 5/31/88

BY

		MOD'D	STD	UMOD	
1	30:00	84.8	85.2	85.5	RH 35% Sun 82-84
2	32:00	84.7	85.2	85.2	
3	34:00	82.6	83.8	82.7	
4	36:00	83.3	83.7	84.1	
5	38:00	83.8	85.4	84.5	1 seconds later - all read
6	40:00	84.1	84.4	84.2	Sun 82, 84 (86.0) RH - 32% each one
7					
8					
9					
10					
11					
12					
13					
14	Sun behind & to left; sun shone on LHS of pistol —				
15	so far, no noticeable diff due to sun load; LHS notably				
16	warm — RHS notably cool to touch.				
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					
29					
30					
31					
32					
33					
34					
35					
36					
37					
38					

Test 2, same pistols - rotated so sun hits Rhts (sensor side). After sitting outside w/out fans on, for 2 hrs. Units on for several minutes before test starts (ie, ~5 mins). Units' Rhts exposed to sun only ~~after~~ " after machines on.

TIME	MOD'D	STD	UNMOD	[Looking for solar bias.]
0:00	87.9	88.0	88.0	
2:00	86.6	86.5	87.4	
3:00	88.4	87.7	88.7	
4:00	87.0	86.6	87.7	← Unmod runs ½ - 1°F hotter than mod'd, typ. Both higher than shaded Std.
~~5:00~~	89.0	88.3	89.3	
~~6:00~~ 7:00	86.3	86.6	86.2	
8:00	86.9	86.0	86.2	
9:00	87.1	87.3	87.6	
10:00	86.8	86.6	87.8	
11:00	87.5	87.0	88.0	

@12:00, BRG removed from holder, held ~~55~~ 5

~~24:0~~ 22:12 guns across board

8	84.7	85.9	84.7	
	87.5	85.7	89.9	24:00

CLV 193-C

SHEET NO. ____ OF ____

FILE ____

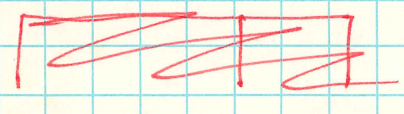
SUBJECT ____

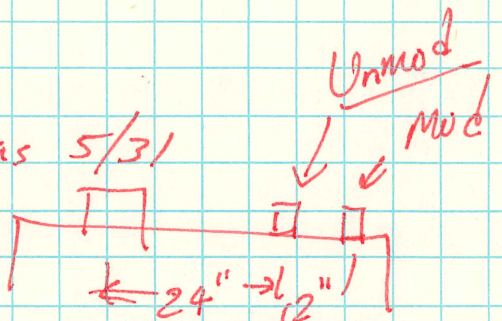
DATE 6/1/88

BY CJB

Winds 0-5, gusting to 10 mph
~85°F
RH 33%

Equil. of same two units as 5/31





Time	STD	Unmod	Mod
2:10	83.1	92.0	92.8
2:40	84.2	90.6	87.4
3:10	84.1	93.2	89.9
3:40	85.0	93.8	90.5
4:10	86.1	97.0	94.9
4:40	85.7	96.2	94.6
5:10	84.8	91.7	90.4
5:40	86.0	93.1	91.6
6:10	85.4	91.8	91.7
6:40	85.0	91.8	89.9
7:10	85.3	92.4	90.6
7:40	85.4	90.5	88.7
8:10	83.6	86.2	86.3
8:40	83.8	84.6	84.8
9:10	85.9	90.4	89.3
9:40	83.2	84.0	83.7
10:10	84.4	86.9	86.0
10:40		84.6	84.5
~~11:10~~			
~~11:40~~	Units timed out/countdown		
~~12:10~~			
12:40	89.0	88.7	88.4
13:10	84.8	85.5	85.0
12:40	83.5	84.9	84.5
14:10	85.2	87.4	86.6
14:40	84.3	85.0	84.8
15:10	84.0	85.6	85.3

Time Ø was when units brought to "horse" - both were exposed to air from car (not bagged) - 58°

Units seem sensitive to wind speed

CLV 193-C

SHEET NO. 2 OF

FILE

SUBJECT

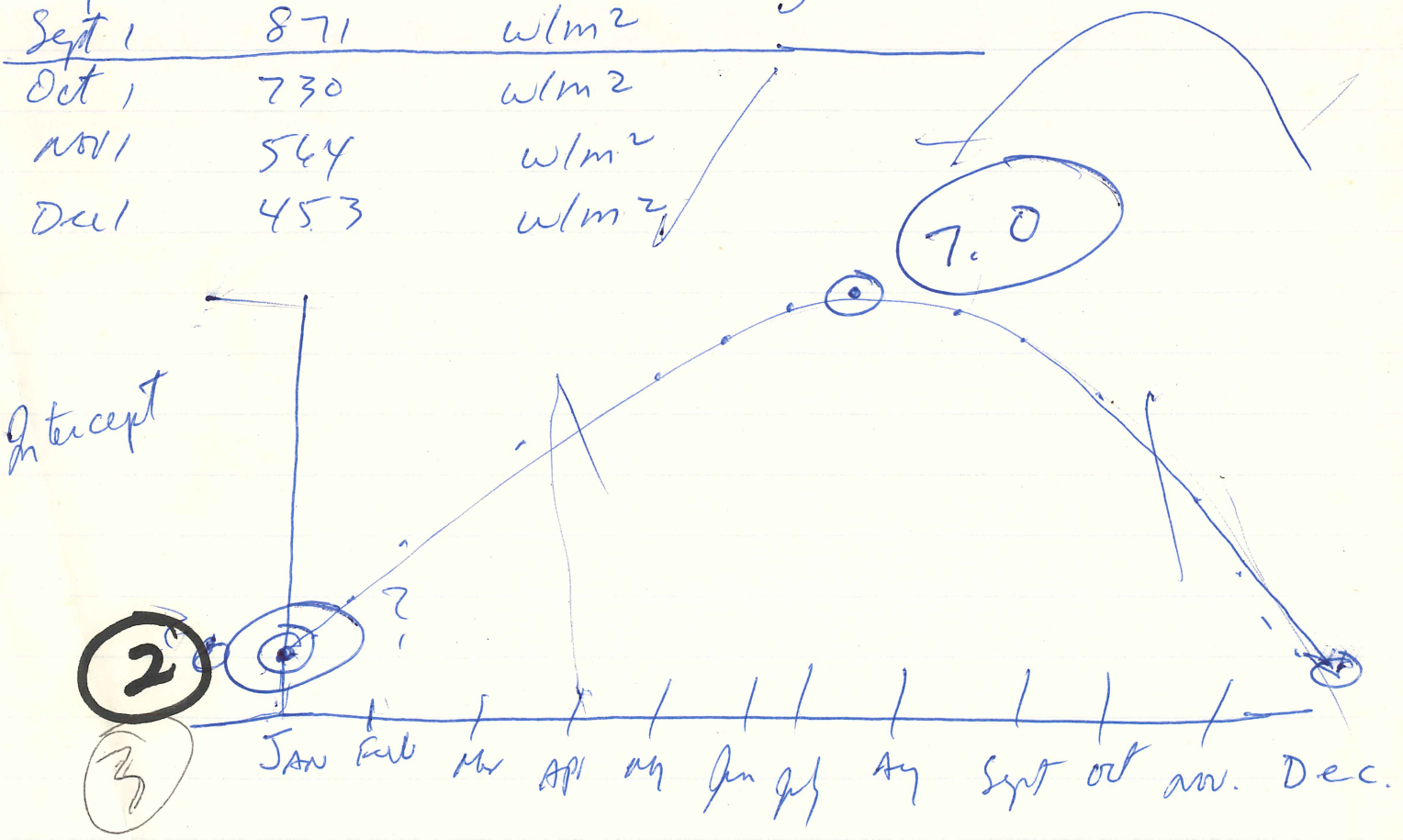
DATE 6/1

BY CTS

		SID	UnMod	Mod
1	15:40	84.0	84.3	84.5
2	16:10	85.1	86.5	86.1
3	16:40	86.1	87.9	87.3
4	17:10	85.6	87.0	87.0
5	17:40	85.9	87.6	87.3
6	18:10	86.9	88.4	87.8
7	~~18:40~~ →	83.7	84.1	84.3
8	19:10	~~- - - -

33°N Latitude

Solar Noon (Incoming Radiation)

Jan 1	442	w/m²
Feb 1	540	w/m²
Mar 1	687	w/m²
April 1	843	w/m²
May 1	938	w/m²
June 1	977	w/m²
July 1	980	w/m²
Aug 1	953	w/m²
Sept 1	871	w/m²
Oct 1	730	w/m²
Nov 1	564	w/m²
Dec 1	453	w/m²

7° one